THE PENNSYLVANIA RAILROAD SYSTEM

AT THE

LOUISIANA PURCHASE EXPOSITION

LOCOMOTIVE TESTS

AND

EXHIBITS

SAINT LOUIS, MISSOURI, 1904

FIRST EDITION

PHILADELPHIA
THE PENNSYLVANIA RAILROAD COMPANY
1905

GIFT OF
C. A. MOORE

INTRODUCTION.

The exhibit of the Pennsylvania Railroad System at the Louisiana Purchase Exposition was designed primarily to show the application of Civil and Mechanical Engineering to the needs of a large railroad.

In the field of Civil Engineering there were shown models and drawings of work already accomplished and under construction.

As an example of Mechanical Engineering the locomotive testing plant was presented.

The idea of making tests of a locomotive with its wheels free from the rails and its work absorbed by external means, originated with Alexander Borodin, in Russia. Entirely without knowledge of these early experiments, however, Professor Goss conceived the idea of running a locomotive on supporting wheels and in a laboratory where conditions could be kept constant and without the interruption and variations found in road tests. His ideas were carried out at Purdue University by the installation, under his supervision, of a locomotive testing plant. The value of his experiments and conclusions has long been acknowledged.

In the testing plant erected at St. Louis, sufficient capacity and flexibility were provided to accomodate locomotives of widely varying types and dimensions. It was expected originally that such a plant would serve merely as an exhibit which, after the close of the Exposition, would be given a permanent location on the company's property and utilized in the study of locomotive design. Further development of this idea, however, led to the determination to carry on at St. Louis a series of tests and endeavor to enlist the interest of the engineering profession and railroad companies in making them as comprehensive as possible. The results are contained in the present volume.

It was, at first, intended to publish separately the data obtained from the tests of each locomotive when completed; this was done, however, only in the case of the first locomotive and the results are contained in a bulletin published during the early part of the present year. It was later decided that the better plan would be to combine in one publication the results of the whole series of tests.

An inspection of the chapters relating to the tests will show that the data obtained from each locomotive have been arranged and presented according to a definite plan, facilitating reference to similar items and related facts.

The ready co-operation of the American Society of Mechanical Engineers and the American Railway Master Mechanics' Association in appointing the members of the Advisory Committee, made it possible to obtain counsel and advice which have been of the greatest value in planning and carrying out the tests.

The Pennsylvania Railroad System acknowledges the valuable services rendered by the Advisory Committee. Not only has it aided greatly in all phases of the work, but its members individually, and especially its Chairman, have given at all times most willing help, covering a long period of time in which many perplexities occurred.

To the President and Officers of the Louisiana Purchase Exposition for the liberal spirit in which they assisted in many ways towards the success of this undertaking, grateful acknowledgement is made.

To the operating staff and testing force, by whose untiring efforts and faithfulness to duty the work has been executed, the thanks of these companies are extended.

Signed:

THE PENNSYLVANIA RAILROAD SYSTEM.

Philadelphia, Pa., U. S. A.
November 1, 1905.

RESOLUTIONS OF THE ADVISORY COMMITTEE.

At the meeting of the Advisory Committee held at Broad Street Station, Philadelphia, June 12th, 1905, the following preamble and resolutions were presented by the Secretary and unanimously adopted:—

THAT WHEREAS: The Advisory Committee, representing various scientific and technical interests in the tests of locomotives at the Louisiana Purchase Exposition, having completed its formal work, and desiring to express its appreciation of the action of the Pennsylvania Railroad System in conceiving, planning and executing these tests, now makes of record the fact, that:

The Pennsylvania Railroad System has brought into existence an entirely new testing plant designed for mounting either freight or passenger locomotives, and capable of absorbing for an indefinite period the maximum power of a modern locomotive when running at any rate of speed between 10 and 75 miles per hour:

It has caused to be designed and constructed a dynamometer capable of registering the tractive power of the heaviest locomotives, and at the same time so sensitive as to indicate the slightest variation in the force it may exert;

It has purchased and standardized instruments and apparatus for use in securing all data which has been deemed to be of scientific interest;

It has organized a complete corps of observers, engineers and computers to carry out the tests, and to record, tabulate and analyze the results;

It has invited and secured the co-operation of scientific and technical men of this and other countries to assist in placing the tests upon the highest scientific plane possible in such work;

It has overcome difficulties, in many cases perplexing and serious, incident to the carrying out of such a work as a part of a great International Exposition;

It has, as a result of its effort, defined the action of eight different typical locomotives as regards the performance of the boiler, the engine, and of the locomotive as a whole, under many different conditions of operation, making of record a mass of information concerning the economic performance of the modern locomotive of great immediate value, and supplying a basis of comparison which will prove useful for many years to come;

It has met the expenses of equipping and operating the plant with an unstinted hand, always holding considerations of cost subordinate to the definite object of making the tests as complete and valuable as possible, notwithstanding the fact that the amounts involved have been far greater than have ever been appropriated to any similar undertaking; and

It has undertaken a broad plan of publication which is to result in making all its data derived from tests, and all conclusions based thereon, together with a description of methods and means employed, all in great detail, accessible to railroad officials and locomotive designers throughout the world;

THEREFORE, BE IT RESOLVED, THAT the Advisory Committee expresses its appreciation of the part taken by the organized staff concerned in conducting this work;

It recognizes that special credit is due to Mr. J. J. Turner, Third Vice-President, and Mr. Theo. N Ely, Chief of Motive Power, for their efforts in securing the interest and the favorable action of the Pennsylvania Railroad System in behalf of the proposed work, for the broad views which have prompted them in giving it their general direction, and for the interest they have shown in the maintenance of the high standards which have marked its progress;

To Mr. F. D. Casanave, for the able manner in which he has effected a working organization, for his successful efforts in securing locomotives to be tested, for the skill, earnestness and freedom from friction with which he has managed the entire work;

To Mr. A. W. Gibbs, for his enthusiastic personal support, and for the fullness with which he has made available the resources of the Motive Power Department;

To Mr. A. S. Vogt, for a design of testing plant of unusual beauty and perfection of details, and of such excellence in operation that under severe conditions of service, interruptions were more frequently due to locomotive defects than to difficulties with the plant;

To Mr. E. D. Nelson, for the efficiency with which he organized and managed the expert staff, and for the ability shown in dealing with all scientific questions involved;

To Mr. G. L. Wall and his efficient staff of assistants for the devotion shown in the operation of the plant, their ability and determination in overcoming difficulties, their skill in maintaining running conditions, and their painstaking efforts in securing accuracy in results.

SIGNED:

W. F. M. Goss,
H. H. Vaughan,
J. E. Sague,
E. M. Herr,
F. H. Clark,
C. H. Quereau,
H. V. Wille,
W. A. Smith,
Advisory Committee

CONTENTS.

PAGE

ORGANIZATION 1

PRIZES 3

EXHIBITS 7

LOCOMOTIVE TESTING PLANT 24

APPARATUS AND INSTRUMENTS 42

THE ADVISORY COMMITTEE 62

OPERATING FORCE 66

PLAN AND SCOPE OF TESTS 69

CALIBRATION OF INSTRUMENTS 72

METHODS OF RECORDING TESTS 76

METHODS OF CONDUCTING TESTS 107

SELECTION OF LOCOMOTIVES 112

INSTALLATION AND PRELIMINARY OPERATION 117

INTERRUPTIONS AND DELAYS 119

TESTS OF CONSOLIDATION LOCOMOTIVE, PENNSYLVANIA RAILROAD COMPANY 124

PAGE

TESTS OF CONSOLIDATION LOCOMOTIVE, LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY 196

TESTS OF CONSOLIDATION LOCOMOTIVE, MICHIGAN CENTRAL RAILROAD COMPANY......... 265

TESTS OF "SANTA FE" TYPE LOCOMOTIVE, ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM 331

TESTS OF DE GLEHN ATLANTIC TYPE LOCOMOTIVE, PENNSYLVANIA RAILROAD COMPANY..392

TESTS OF ATLANTIC TYPE LOCOMOTIVE, ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM 463

TESTS OF ATLANTIC TYPE LOCOMOTIVE, HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT 542

TESTS OF ATLANTIC TYPE LOCOMOTIVE, NEW YORK CENTRAL & HUDSON RIVER RAILROAD.615

COMPARISONS AND CONCLUSIONS................687

ORGANIZATION.

THE PENNSYLVANIA RAILROAD SYSTEM:

J. J. Turner, Third Vice President, Pennsylvania Lines West of Pittsburgh.

Theo. N. Ely, Chief of Motive Power, Pennsylvania Railroad System.

F. D. Casanave, Special Agent, Pennsylvania Railroad System.

E. D. Nelson, Engineer of Tests, Pennsylvania Railroad Company.

THE LOUISIANA PURCHASE EXPOSITION:

Willard A. Smith, Chief of the Department of Transportation Exhibits, Louisiana Purchase Exposition.

ADVISORY COMMITTEE:

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS:

W. F. M. Goss (Chairman), Dean of the Schools of Engineering, Purdue University.

Edwin M. Herr, General Manager, Westinghouse Air Brake Company.

J. E. Sague, First Vice President, American Locomotive Company.

THE AMERICAN RAILWAY MASTER MECHANICS' ASSOCIATION:

F. H. Clark, Genl. Superintendent of Motive Power, Chicago, Burlington & Quincy Railroad.

C. H. Quereau, Superintendent of Shops, New York Central & Hudson River Railroad.

H. H. Vaughan (Secretary), Superintendent of Motive Power, Canadian Pacific Railway.

During Mr. Quereau's absence from duty in the months of August, September, October and November, Mr. F. M. Whyte, Mechanical Engineer, N. Y. C. & H. R. R., was appointed by the Executive Committee of the American Railway Master Mechanics' Association to serve on the Advisory Committee.

AFFILIATED MEMBERS:

John A. F. Aspinall, General Manager, Lancaster & Yorkshire Railway, England.

Karl Steinbiss, Director, Royal Prussian Railway, Altona, Germany.

H. V. Wille, Assistant Superintendent, Baldwin Locomotive Works.

OPERATING FORCE.

F. D. Casanave, Special Agent.
P. W. Sullivan, Secretary.

E. D. Nelson, Engineer of Tests.
G. L. Wall, Director of Tests.
G. E. Rhoads, Assistant Director of Tests.
C. Ducas, Editor.
G. B. Koch, Foreman of Plant.
O. P. Reese, Foreman of Tests.
C. S. McIntyre, Stenographer.

P. H. Bates, Chemist, C. D. Young, Chief Computer, C. D. Porter, Observer, B. S. Murphy, Observer, D. W. McKelvey, Observer, P. H. Graham, Dynamometer Observer, T. L. Mallam, Brake Operator, L. C. Burket, Computer, J. E. Roller, Computer, F. M. Weakley, Draftsman, A. M. Kratz, Draftsman, Thos. Russell, Machinist, J. L. McQuade, Craneman, B. M. Kincaid, Engineman, R. W. Coulter, Engineman, N. Suhrie, Fireman, W. C. McNeal, Fireman.

In addition to the permanent force given above there were 40 observers who remained about two months each, and several enginemen and firemen who remained for varying periods of time.

PRIZES

AWARDS MADE BY THE LOUISIANA PURCHASE EXPOSITION.

1st.—A Special Commemorative Grand Prize awarded to the Pennsylvania Railroad System for its original series of scientific investigations of locomotive performance conducted at the Louisiana Purchase Exposition, the methods and results of which are a permanent contribution to the advancement of engineering knowledge.

The Committee of Five, composing the Superior Jury, "was unanimous in this action, and each member individually expressed his high appreciation of the magnificent work done by the Pennsylvania Railroad "System in establishing and conducting this testing "plant."

2nd.—In the Department of Liberal Arts, Group 26:—

A Grand Prize for the Model of the Terminal Passenger Station in New York City.

3rd.—In the Department of Transportation Exhibits, Group 74:—

A Grand Prize (a) The Locomotive Testing Plant and Laboratory.

A Grand Prize (b) The Railway Postal and Mail Car.

A Grand Prize (c) The Model of the West Philadelphia Terminal.

A Grand Prize (d) The Model of the New York and Long Island Railroad Tunnels.

A Grand Prize (e) Full Sized Section of Tunnel under the North and East Rivers.

A Grand Prize (f) Exhibit of Maps and Drawings illustrating the following improvements made on the Pennsylvania Railroad, viz.:

(1) Change of Line at Irwin, Pa., on the Pittsburgh Division.

(2) Brilliant Branch of the Pennsylvania Railroad through the City of Pittsburgh.

(3) Change of Line at Coatesville, Pa., and Stone Arch Bridge over the Brandywine Creek on the Philadelphia Division.

(4) Change of Line East of Duncannon on the Middle Division.

(5) Change of Line from Wilmore to Summerhill on the Pittsburgh Division.

(6) Change of Line from Lilly to Portage on the Pittsburgh Division.

(7) Change of Line at Trenton and Morrisville, N. J., on the New York Division.

(8) Track Elevation at Wilmington, Del., on the Main Line of the Philadelphia, Baltimore & Washington Railroad.

(9) Stone Arch Bridge at Silver Lake on the Brilliant Branch of the Pittsburgh Division.

(10) Stone Arch Bridge at New Brunswick, N. J., on the New York Division.

(11) Rockville Bridge over the Susquehanna River on the Middle Division.

4th.—A Grand Prize to the Societe Alsacienne de Constructions Mecaniques for the DeGlehn four-cylinder balanced compound locomotive.

5th.—A commemorative Gold Medal to the Pennsylvania Railroad System in connection with the exhibit of the DeGlehn four-cylinder balanced compound locomotive.

6th.—In the Department of Social Economy, Group No. 138:—

A Gold Medal for the exhibit of the Pension, Relief and Savings Fund Departments of the Pennsylvania Railroad and the Pennsylvania Lines West of Pittsburgh.

A Gold Medal for the exhibit of the Pennsylvania Railroad Department Young Men's Christian Association of Philadelphia.

7th.—Gold Medals awarded to each of the Collaborators in connection with the preparation of the exhibits and the testing plant:—

Mr. J. J. Turner, Third Vice President, Pennsylvania Lines West of Pittsburgh.

Mr. Theo. N. Ely, Chief of Motive Power, Pennsylvania Railroad System.

Mr. F. D. Casanave, Special Agent, Pennsylvania Railroad System.

Mr. A. W. Gibbs, General Superintendent of Motive Power, Pennsylvania Railroad Company.

Mr. E. D. Nelson, Engineer of Tests, Pennsylvania Railroad Company.

Mr. A. S. Vogt, Mechanical Engineer, Pennsylvania Railroad Company.

Mr. G. L. Wall, Director of Tests, Pennsylvania Railroad System.

Mr. Willard A. Smith, Chief of Department of Transportation exhibits.

Prof. W. F. M. Goss, Dean of Schools of Engineering, Purdue University, Lafayette, Ind.

Mr. Edwin M. Herr, General Manager, Westinghouse Air Brake Company.

Mr. J. E. Sague, First Vice President, American Locomotive Company.

Mr. F. H. Clark, Superintendent of Motive Power, Chicago, Burlington & Quincy Railroad Company.

Mr. C. H. Quereau, Superintendent of Shops, New Central & Hudson River Railroad Company.

Mr. F. M. Whyte, Mechanical Engineer of the New York Central & Hudson River Railroad Company.

Mr. H. H. Vaughan, Superintendent of Motive Power, Canadian Pacific Railway.

Mr. H. V. Wille, Assistant Superintendent, Baldwin Locomotive Works.

Mr. John A. F. Aspinall, General Manager, Lancashire & Yorkshire Railway, England.

Mr. Karl Steinbiss, Director, Royal Prussian Railway, Altona, Germany.

Mr. Chas. M. Jacobs, Chief Engineer, North River Division, Pennsylvania, New York & Long Island Railroad Company.

McKim, Mead & White, Architects, New York Terminal Station.

Klee Brothers, Makers of Model of New York Terminal Station.

Victor Mindeleff, Maker of Models of West Philadelphia Terminal and New York & Long Island Tunnels.

CHAPTER I.

DESCRIPTION OF EXHIBITS.

LOCATION.

The locomotive testing plant and the greater part of the exhibits of the Pennsylvania Railroad System at the Exposition, were located near the southwest end of the Palace of Transportation and occupied 31,185 square feet; the space being 94½ feet wide by 330 feet long. The general arrangement of the principal exhibits is shown by Fig 1.

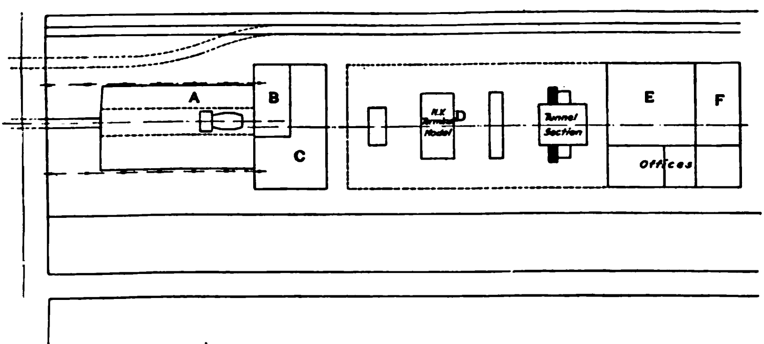


Fig. 1.—General Arrangement of Exhibits.

The space marked (A) was occupied by the locomotive testing plant, description and plans of which will be found in Chap. II.

The space (B) was occupied by a repair shop and chemical laboratory.

The space (C) contained the instrument cases, drawing boards, and was also used as an office by the computers in working up the data.

The large open space marked (D) was surrounded by railings, and in it were located models of the West Philadelphia Terminal Yards, of the New York Terminal Station, of the Pennsylvania, New York & Long Island Tunnel, and a full sized section of this tunnel under the North and East Rivers.

DE GLEHN FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE.

This locomotive was purchased by the Pennsylvania Railroad Company for experimental purposes and was exhibited in its space in the Transportation building. It was designed jointly by Messieurs Alfred De Glehn and Du Bosquet and built by the Societe Alsacienne de Constructions Mecaniques at Belfort, France. It is representative of the highest type of locomotive used in passenger service in France. Illustrations and dimensions will be found in Chap. XVII.

MODEL OF THE WEST PHILADELPHIA TERMINAL YARDS.

This model was made to a scale of 83 1-3 feet to the inch with a vertical exaggeration of 50 per cent. for all railroad features. Its dimensions were 18 feet 6 inches by 8 feet 4 inches. The limits and scope of territory illustrated extends from a short distance east of the Schuylkill River to a point west of 52nd Street, a distance of approximately 3½ miles.

The purpose of the model was to show the methods employed to increase the capacity of a yard originally too small to accommodate existing traffic and adapt it to successfully and safely handle a much larger volume of business. The improvements consisted of additional tracks and relocation of those already in existence, the introduction of overhead structures and subways, which resulted in the separation of the several lines intended for passenger and freight traffic, in such a manner as to eliminate the crossing of all main and yard tracks at grade. On the model was also shown a portion of the elevated freight line starting from a point east of the Main Line, at the 34th Street bridge in West Philadelphia, to Gray's Ferry, a distance of about four miles. The elevated line via the Arsenal Bridge insures free movement to the solid coal trains from the West Philadelphia yards to the Greenwich coal piers, and the elevated branch built over the Philadelphia, Baltimore & Washington Railroad to Gray's Ferry Avenue, gives a direct route for the Southern fruit and fast freight trains to the New York Division tracks without interference with the other lines already described. A number of miniature trains were introduced and distributed

Fig. 2.— Model of West Philadelphia Terminal Yards.

on the model so as to show the direction of traffic and the freedom from interference.

The model was made by the firm of Victor and Jessie L. Mindeleff, of Washington, D. C.

MODEL OF NEW YORK TERMINAL STATION.

The scale of this model was 3/8 of an inch to the foot. Its dimensions were 31 feet by 16 feet and when completed the station will be bounded by 7th and 8th Avenues, 31st and 33d Streets. The model included side-walks to the curb line. Seventh Avenue and 31st Street were modeled complete with the return pavilion adjoining on 8th Avenue and 31st Street. The model was left open between these pavilions on 8th Avenue and 33d Street, showing complete interior sections to the track level through the northwest train shed, restaurant, waiting room and concourse, with the north carriage entrances and offices west of the same.

Three minature trains were shown on the tracks. This model was made by Klee Brothers, of New York, under the supervision of the Architects of the building, Messrs. McKim, Mead & White.

MODEL OF THE PENNSYLVANIA, NEW YORK AND LONG ISLAND TUNNEL.

The scale of this model was 83 1-3 feet to the inch, with a vertical exaggeration of 50 per cent. for all railroad features. Its dimensions were 33 feet by 6 feet, with a depth necessary to show the scope of the work underground.

On the face of the model were shown six cross sections of the tunnel, taken at different points, made to a scale of 1/4 inch to the foot, and one longitudinal section of the tunnel to the same scale, in which was introduced a train consisting of electric locomotive and three passenger cars, typical of the equipment to be used in that tunnel.

The model was made by the firm of Victor and Jessie L. Mindeleff, of Washington, D. C., under the supervision of the Chief Engineers, Messrs. Alfred Noble and Chas. M. Jacobs.

Fig. 3.—Model of New York Terminal Station

Fig. 4.— Model of New York Terminal Station.

FULL SIZE SECTION OF THE NORTH AND EAST RIVER TUNNELS.

The section exhibited was 20 feet long and 23 feet outside diameter. The method of construction and the materials used were the same as will be used in the actual tunnels. A section of a passenger car was inside the tunnel. Steps were provided at both ends to enable visitors to enter the tunnel and car at one end and leave at the other. Pits were provided at each end to show the screw piles supporting the track structure.

The tunnel was erected by The Abbott-Gamble Company of St. Louis, Mo., under the supervision of Mr. Chas. M. Jacobs, Chief Engineer of the North River Division of the Pennsylvania, New York & Long Island Railroad Company.

MAPS, DRAWINGS AND PHOTOGRAPHS.

In the room marked (E), Fig. 1, were maps and blue prints showing recent improvements made on the lines of the Pennsylvania Railroad; also full specifications for the Pennsylvania, New York & Long Island Tunnels, and a number of photographs of scenery along the line of the Pennsylvania Railroad.

On the exterior of the booth were shown photographs of standard locomotives, cars and marine equipment in use on the Pennsylvania Railroad System.

PUBLIC READING ROOM.

The space marked (F), Fig. 1, was devoted to a room for the public, being equipped with writing materials and newspapers from all the principal cities of the country.

YOUNG MEN'S CHRISTIAN ASSOCIATION EXHIBIT.

Photographs and other information were displayed on the walls of this room by the Pennsylvania Railroad Department Young Men's Christian Association of Philadelphia, showing tables of membership of the Association and its organization, the main buildings at 41st Street and Westminster Avenue, with separate views of business offices, reception and reading rooms, library, class rooms, gymnasium, baths, bowling alleys, banquet hall and auditorium; also photographs of the Broad Street Station Annex and of the athletic field at Belmont and Parkside Avenues.

Fig. 5.— Model of New York Terminal Station.

CHANGES ON THE LINE OF THE PENNSYLVANIA RAILROAD.

TRENTON TO MORRISVILLE.

This map illustrated one of the most important changes in line made on the New York Division. The change effected a saving of 785 feet in length over the old line, eliminated five grade crossings and two curves, one of 3° 25′ and one of 4° 00′; reducing the total change of direction by 34° 10′.

WILMINGTON ELEVATED RAILROAD.

This map illustrated the elevation of the tracks of the Philadelphia, Baltimore and Washington Railroad at Wilmington, Delaware, for a distance of three and one-half miles; and the relocation of a section of the line for the purpose of eliminating twenty-four grade crossings of streets, and two railroad crossings; and at the same time effecting a reduction of two curves, one of them from 8° 30′ to a 3° curve.

COATESVILLE.

This map illustrated the present line built south of the former line with a reduction of curvature to 0° 30′. This improvement involved the erection of a new four-track bridge 54 ft. 0 in. wide over copings and 950 feet in length.

DUNCANNON.

This map illustrated a change of line, from east of Duncannon to Aqueduct station, comprising four tracks, each 20,074 feet long, eliminating fifteen grade crossings and effecting a saving of 814 feet in distance and 39° 46′ of change of direction.

LILLY TO PORTAGE.

This map illustrated one of the most radical changes in line made by the Pennsylvania Railroad Company. The length of the former line was a little more than five miles, and the change resulted in a saving of 4,226 feet in distance and a reduction in change of direction of 520° 50′. The former had two 4° 30′ curves, two 5° curves, three 6° curves and one 6° 30′ curve, while the sharpest curve on the new line is 2° 00′.

WILMORE TO SUMMERHILL.

This map illustrated a change of line for four tracks 13,866 feet long, making a saving of 1,704 feet in distance and a reduction in change of direction of 254° 27′. The sharpest curve on the former line was 5° 30′, and on the present line 0° 30′.

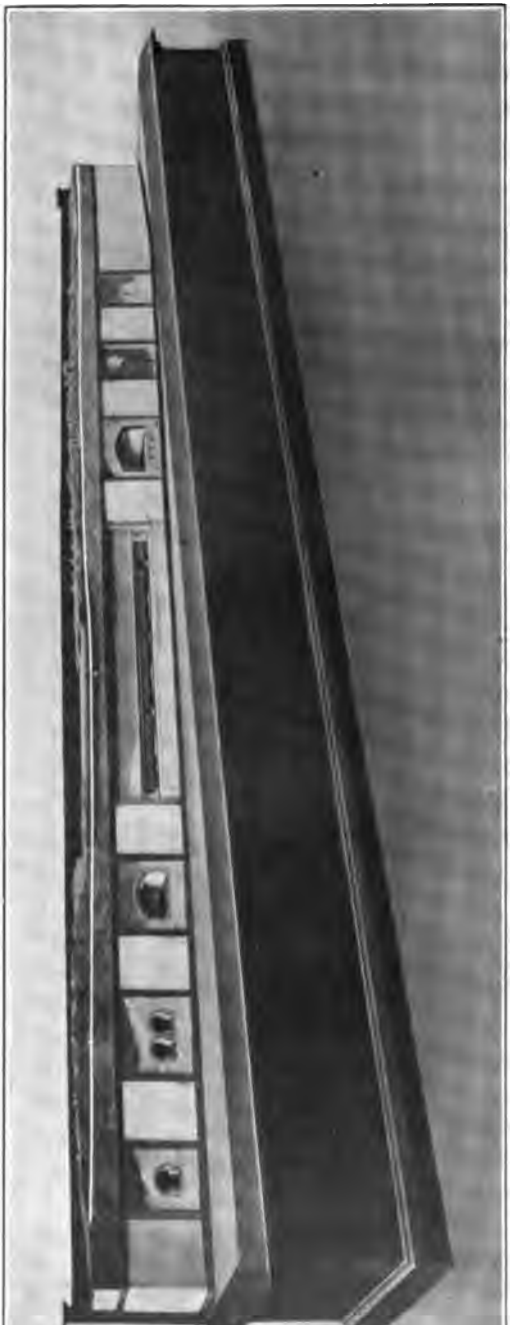


Fig. 6.— Model of the Pennsylvania, New York and Long Island Tunnel.

IRWIN.

This map illustrated a change of line 9,081 feet in length. The present line effected a saving of 931 feet in distance and a reduction of 224° 00′ in change of direction over the former line. There were four curves on the former line, the sharpest of which was 6° 00′, while on the present line there is but one curve of 0° 33′.

Fig. 7.— Full Size Section of the North and East River Tunnels.

BRILLIANT BRANCH.

This map illustrated an improvement in the City of Pittsburgh which completed a belt line around the city.

SILVER LAKE STONE ARCH BRIDGE.

This map illustrated the four-track bridge over a ravine on the Brilliant Branch. Its length is 800 feet. It consists of five semi-circular arches of 80 feet span each, one semi-circular arch of 100 feet span, and a girder bridge 300 feet in length.

NEW BRUNSWICK STONE ARCH BRIDGE.

This map illustrated the four-track bridge at New Brunswick, New Jersey, over the Raritan River. The length of the masonry is 1,500 feet, and the width 57 feet over copings.

ROCKVILLE BRIDGE.

This map illustrated the four-track stone arch bridge across the Susquehanna River, west of Harrisburg. It is the longest stone bridge in the world. It consists of 48 arches each of a span of 70 feet. The length is 3,830 feet and the width 52 feet over copings.

THE PENNSYLVANIA RAILROAD VOLUNTARY RELIEF AND PENSION DEPARTMENTS, AND EMPLOYEES' SAVING FUND.

THE VOLUNTARY RELIEF AND PENSION DEPARTMENTS OF THE PENNSYLVANIA LINES WEST OF PITTSBURG.

This exhibit was made in the Department of Education and Social Economy. In addition to the charts there were also exhibited copies of the annual reports, regulations and other literature bearing on the various subjects.

Fig. 8 illustrated the growth, by years, of the Voluntary Relief Department of the Lines East of Pittsburgh, from the date of its inauguration, February 15, 1886, to December 31, 1903, showing membership, amount of contributions received from and benefits paid to members during the eighteen years of operation. The receipts for the entire period from all sources aggregated $14,639,092.54, benefits paid aggregated $11,553,507.78, and the expense of operation, which was borne entirely by the Railroad Companies associated, amounted to $1,815,641.54.

Fig. 9 illustrated the growth, by years, of the Voluntary Relief Department of the Lines West of Pittsburgh, from the date of its inauguration, July 1, 1889 to December 31, 1903, showing membership, amount of contributions received from and benefits paid to members during the fourteen and one-half years of operation. The receipts for the entire period from all sources aggregated $4,452.460.30, benefits paid aggregated $4,221,709.97, and the expense of operation, which was borne entirely by the Railroad Companies associated, amounted to $754.607.81.

The Pennsylvania Railroad Voluntary Relief Department.

Tables showing Membership, Contributions Received and Benefits paid, from its organization on Feb. 15, 1886, to Dec. 31, 1903.

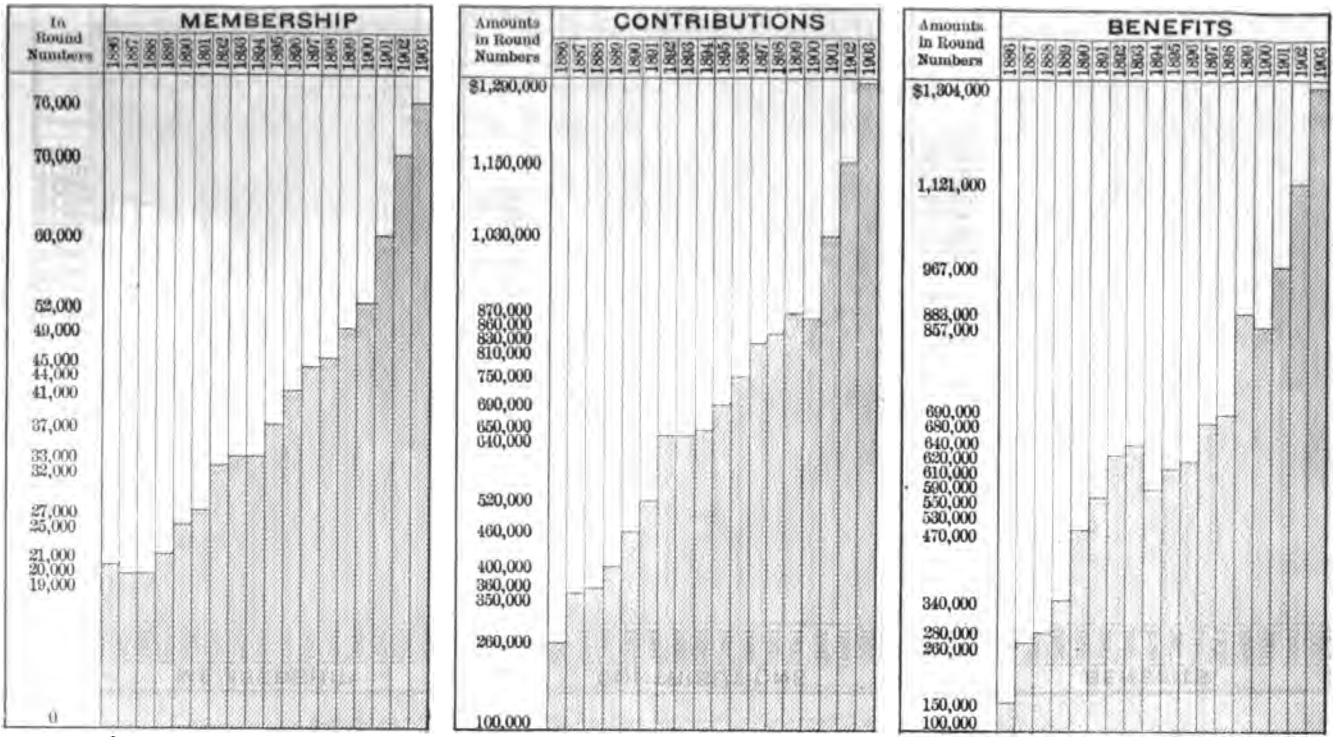


Fig. 8. **Office of the Superintendent, 233 So. 4th St. Annex, Philadelphia, Pa., U. S. A.**

The Pennsylvania Lines West of Pittsburg Voluntary Relief Department.

Tables showing Membership, Contributions Received and Benefits Paid, from its Organization July 1, 1889, to Dec. 31, 1903.

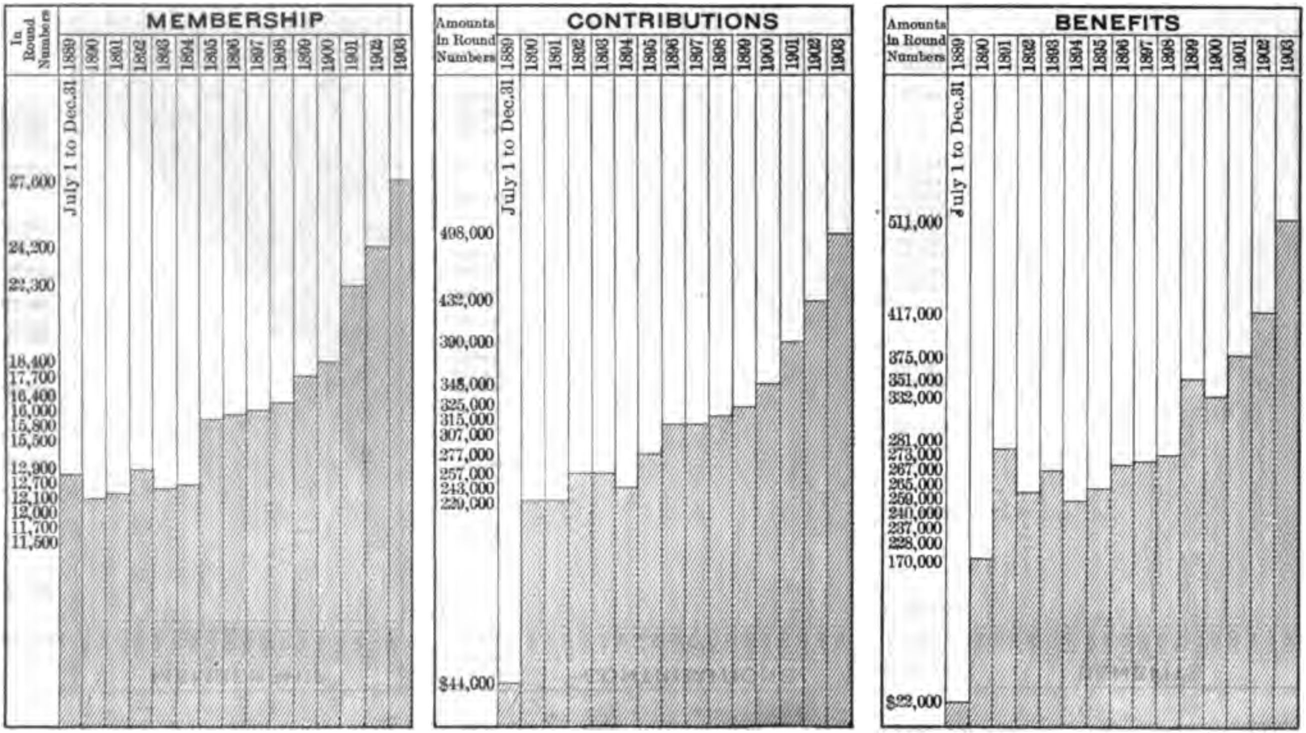


Fig. 9. **Office of the Superintendent, American Trust Building, Cleveland, O., U. S. A.**

The Pennsylvania Railroad Pension Department.

Tables showing Number of Employes, Totals of the Pay Rolls, Number of Pensions and Pension Allowances Paid.

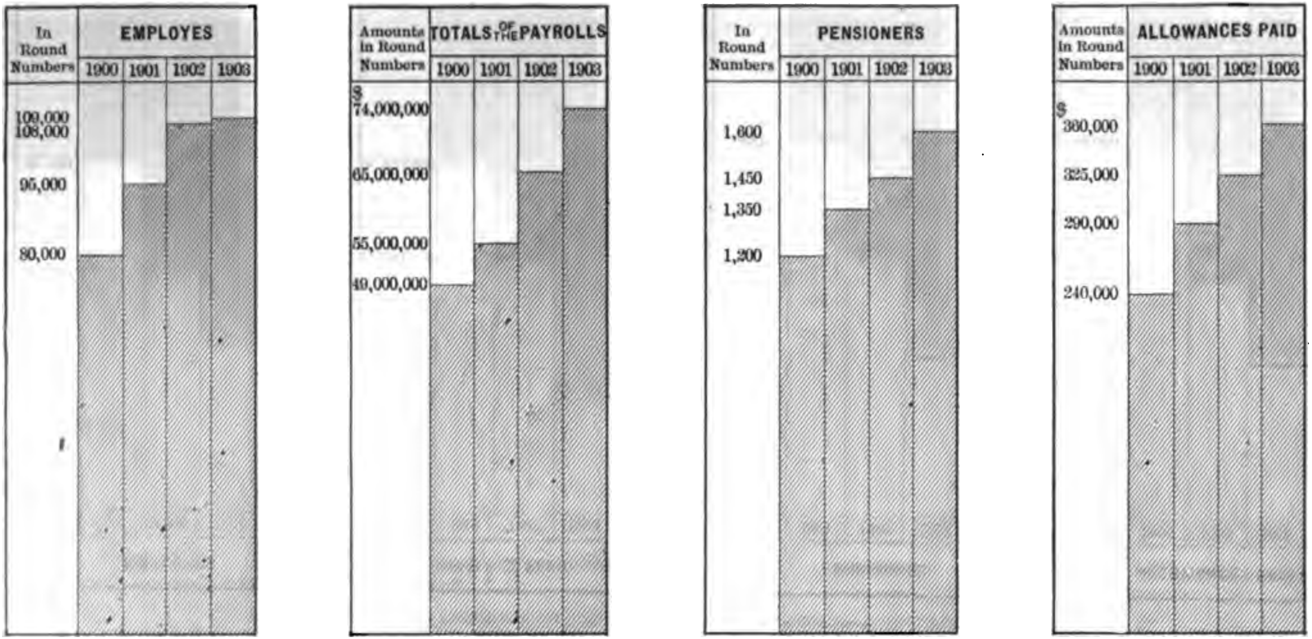


Fig. 10. **General Office. Broad Street Station, Philadelphia, Pa., U. S. A.**

The Pennsylvania Lines West of Pittsburg Pension Department.

Tables showing Number of Employees, Totals of the Pay Rolls, Number of Pensioners and Pension Allowances Paid From its Organization January 1, 1901, to December 31, 1903.

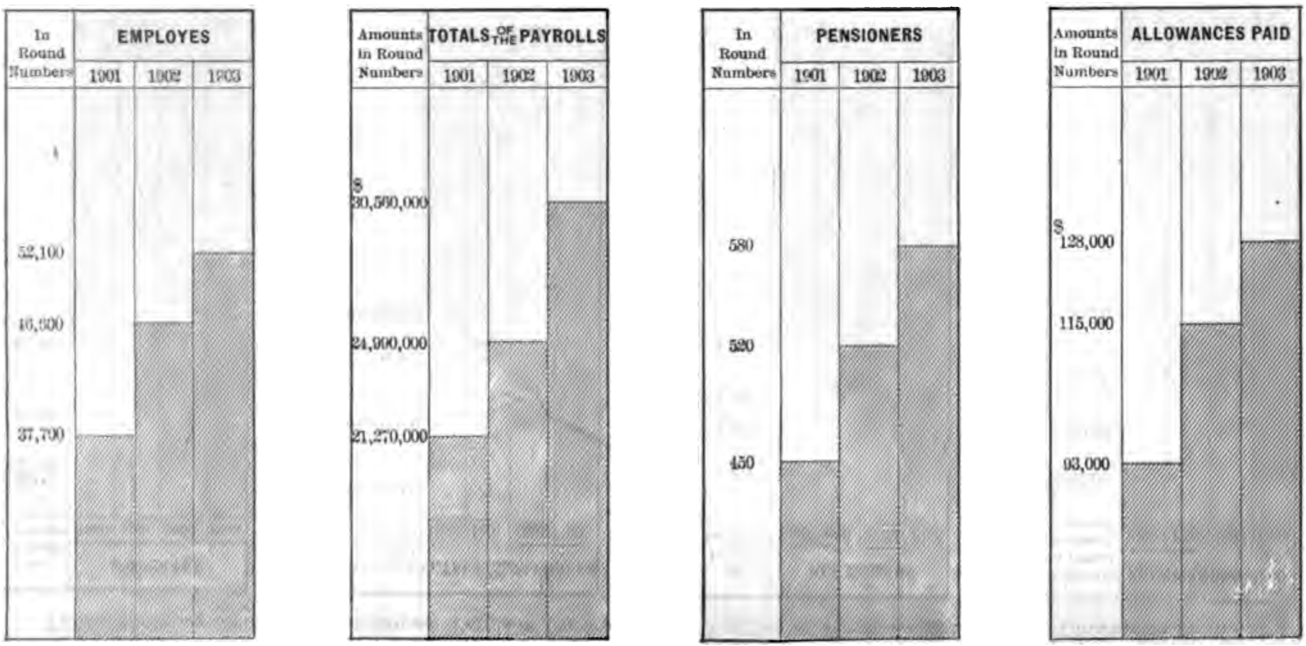


Fig. 11.

General Office, Union Station, Pittsburg, Pa., U. S. A.

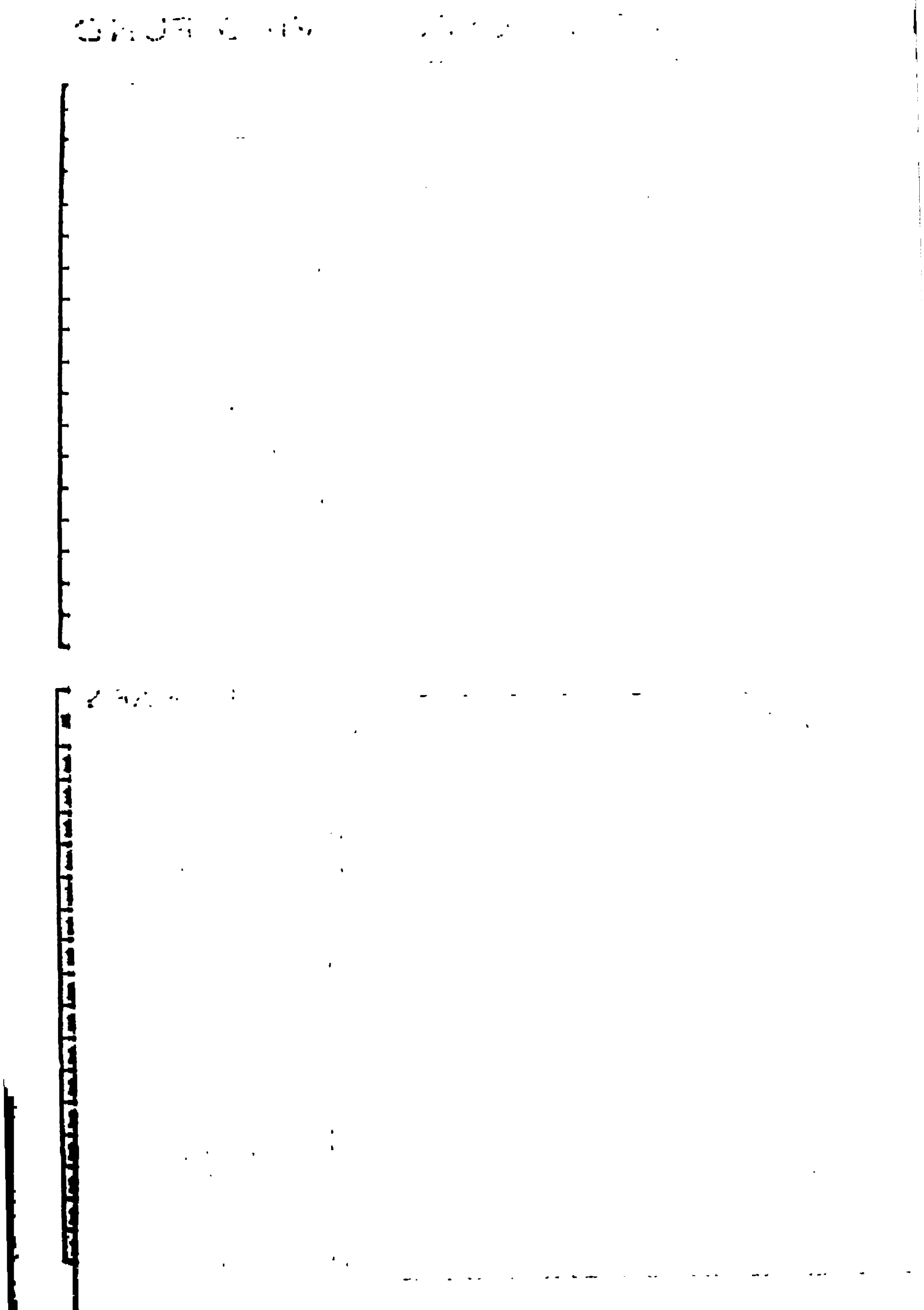


Fig. 12.

Fig. 10 illustrated the growth, by years, of the Pension Department of the Lines East of Pittsburgh, from the date of its inauguration, January 1, 1900 to December 31, 1903, showing the number of employes, their aggregate annual compensation, number of pensioners, and amount of pension allowances paid. The total number of pensions in force December 31, 1903 was 1,599, and the total number of employes retired on pension allowances since the inauguration of the Department to December 31, 1903, was 2,126, there being 527 cessations on account of death. The pension allowances paid during the entire period amounted to $1,224,087.59.

Fig. 11 illustrated the growth, by years, of the Pension Department of the Lines West of Pittsburgh, from the date of its inauguration January 1, 1901, to December 31, 1903 showing the number of employes, their aggregate annual compensation, number of pensioners, and amount of pension allowances paid. The total number of pensions in force December 31, 1903, was 579, and the total number of employes retired on pension allowances since the inauguration of the Department to December 31, 1903, was 652, there being 73 cessations on account of death and other causes. The pension allowances paid during the entire period amounted to $336,227.85.

Fig. 12 illustrated the growth, by years, of the Pennsylvania Railroad Employes' Saving Fund, from the date of its inauguration, January 2, 1888 to December 31, 1903, showing the total number of depositors, amount of deposits, withdrawals, and interest allowed on deposits during the sixteen years of operation. The number of depositors in the Fund December 31, 1903 was 9,494, and the total amount in the Fund was $4,010,116.88.

POSTAL LETTER CAR.

In the Government Building was exhibited a Pennsylvania Railroad standard 60 ft. mail car which was used as a local post office by the United States Government during the entire period of the Exposition.

The purpose of the authorities of Post Office Department was to give the public the opportunity to see the methods employed in handling, sorting and distributing the mails. In order to place the operations in full view of visitors, one side of the car was left open, being only covered with wire netting for protection.

CHAPTER II.

DESCRIPTION OF THE LOCOMOTIVE TESTING PLANT.

The design of the locomotive testing plant was intrusted to Mr. A. S. Vogt, Mechanical Engineer, of the Pennsylvania Railroad Company under the direction of Mr. A. W. Gibbs, General Superintendent of Motive Power, and work on the plans was begun in August, 1903. Although the design for the plant was prepared at Altoona and much of the work done in the shops of the Company at that point, certain parts were made at shops of outside manufacturers. The firm of Wm. Sellers & Company, Incorporated, co-operated with the Mechanical Engineer of the Pennsylvania Railroad in the design of the dynamometer, bed-plates, pedestals and pedestal boxes.

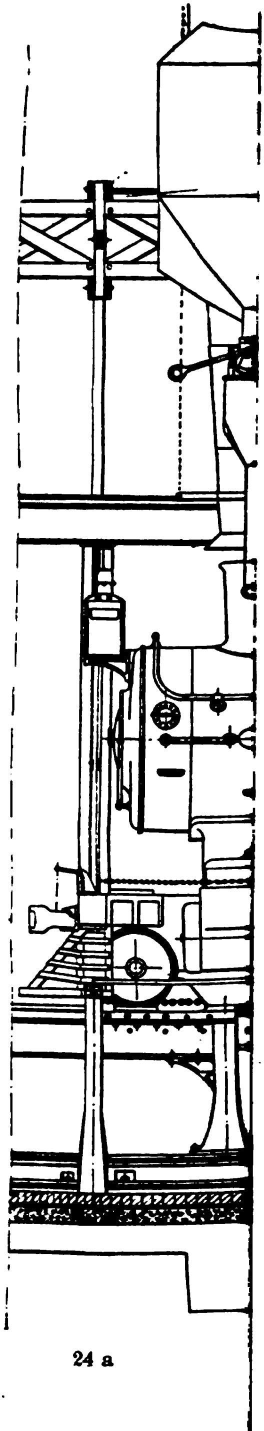
FOUNDATIONS.

The foundation plans and cross sections are shown in Fig. 14. The foundation marked A was for the dynamometer and BB for the bed-plates.

The contour of the foundations is shown in the section marked GH. The greatest stress being immediately forward of the dynamometer foundation, 60 corrugated steel bars 22 feet long were used for reinforcing the concrete.

The pockets in the dynamometer foundation were for lugs on the base of dynamometer castings, and were designed to relieve the dynamometer foundation bolts of shearing stresses.

The foundation marked C was for the end of the extension track and the foundations D, D, etc., were for the cast iron columns supporting the removable flooring. The columns were also used as brake pipe carriers; and the foundations marked E, E, etc., were for the posts which supported the crane runway. Between these posts was the wall of the pit, made of concrete 2 feet thick and having an offset 14 inches below the top



24 a

Fig. 13.

Elevation of Testing Plant.

to serve as a support for the removable flooring. The other side of the flooring was carried on I beams supported by the columns, D, D, etc.

The pit was large enough to provide room for the storage of the supporting wheels, axles, brakes and pedestals which were not in use, and also for such other supplies and appliances as were necessary for the operation of the plant. The floor covering this storage pit, was made in sections, so that any portion could be removed as occasion required. The central portion of the pit, however, was entirely open with the exception of two longitudinal platforms on which the observers stood to secure indicator cards and make observations of temperatures and obtain other information of this character.

A six inch water main was laid along the north side of the foundation, rising above the floor at Q. Drains were in the space between the bed-plates and storage pits, and are shown in the section, K L. There were 1,250 cubic yards of earth excavated for the plant and 500 cubic yards of concrete were laid.

BED FOR PEDESTALS.

The base of the plant consisted of two longitudinal cast iron bed-plates, as shown in Fig. 15. These were secured to the concrete foundations which resisted the shocks transmitted from the locomotive driving wheels. The bed-plates were provided with longitudinal T slots and the pedestals were secured to them by 1½ inch bolts thus permitting adjustment lengthwise, so that the position of the supporting wheels could be adjusted to correspond with the spacing of the driving wheels of the locomotive.

PEDESTALS.

Two sets of pedestals were necessary—a high pedestal for the 50 in. supporting wheels, and a low pedestal, as shown in Fig. 16 for the 72 in. wheels—the object being to have the level of the top of supporting wheels the same for each set of pedestals.

The pedestal box rested on a ring A, the top surface of the ring being a segment of a sphere. The ring was free to turn around the vertical axis of the pedestal, and therefore the box was free to adjust itself both horizontally and vertically.

The lower surface of the upper binding screw was also spherical. This method of supporting the box prevented the axle from binding and the ring support provided a means for raising the supporting wheel by using liners, when turning the tires made this necessary.

The high pedestal is similar in construction to the one shown.

The method of attaching the oil cups to the pedestal box is shown in broken lines. There were three oil cups to each box.

PEDESTAL BOXES.

The pedestal boxes shown in Fig. 18 were made of soft gray cast iron, with a bushing of "Plastic Bronze." The parts of the box which were held by the pedestal were segments of a sphere. The cast iron cap did not touch the axle but had an original clearance of .03 in., and later the boxes were bored 1-32 in. larger, so that the clearance was increased. The lower half of the journal box was provided with passages J for circulating cooling water, when necessary. The slots in the bushings were intended to take up expansion due to heating and hence lessen the tendency to bind the axle. Felt pads in the grooves K served as oil distributors and as a means to catch particles of grit.

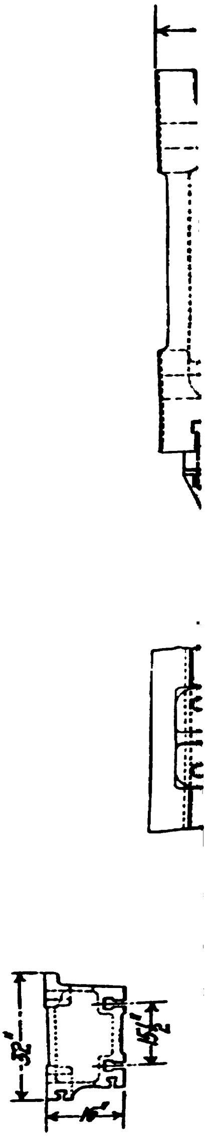
Both ends of the boxes were designed to act as dust guards, fitting closely to the nut which held the brake at the outer end. One end of the box projected under the dust guard on the wheel at the inner end.

The boxes and axles were made by different manufacturers and to insure perfect fit a gauge was made to which the bushings and axles were fitted.

The square grooves near the edges of the lower half of the boxes were intended to prevent the oil from leaking out at the sides, these grooves returning the oil to the oil pockets.

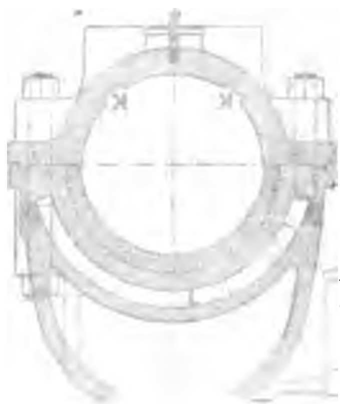
SUPPORTING WHEELS.

The locomotive under test was carried on supporting wheels, the axles of which were extended to receive absorption brakes. The turning of the driving wheels caused the supporting wheels to revolve and these were retarded by the brakes. The work actually done by the locomotive consisted in overcoming the frictional resistance of the supporting wheels and brakes, the resulting force exerted at the draw-bar being measured by a traction dynamometer. The upper faces of the supporting wheels were at the level of the tracks and of the floor of the building. There were two sets of supporting wheels, one consisting of



26 a

Fig. 15



standard 100 lb. rail, the form of the rest of the tire being designed to throw off oil that might fall on the tire, and prevent its reaching the tread of the wheel.

The supporting wheel centers were made of cast steel, thoroughly annealed; the tires were shrunk on and held by a bolted retaining ring.

The ¼ inch square groove A outside the spokes was pro-

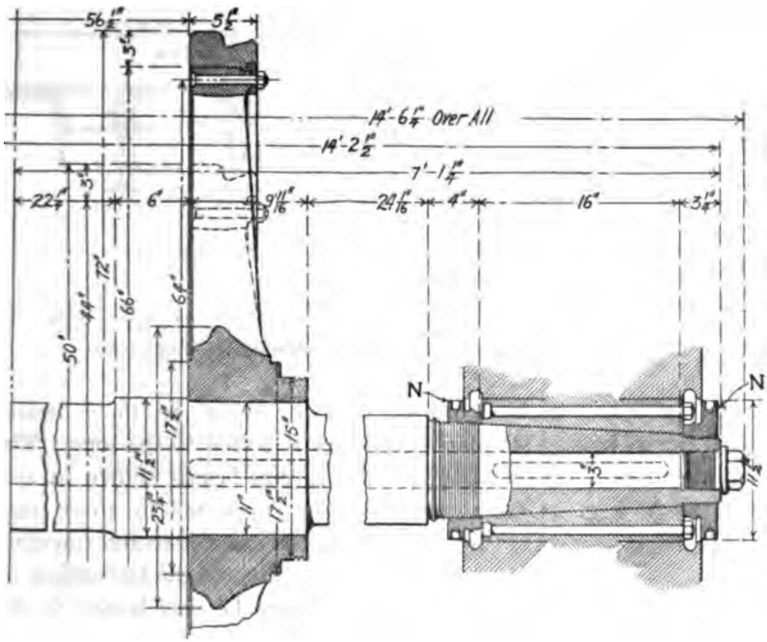


Fig. 19.—Supporting Wheel and Axle.

vided for a cast iron dust guard, the lip of which projected over the end of the journal box.

The two V shaped grooves B were intended to prevent oil from the axle reaching the wheel.

Fig. 19 shows the wheel on the axle, and the brake in position with the spanner nuts N on each side of the brake.

EXTENSION AND REMOVABLE TRACKS.

The truck wheels of the locomotive under test did not revolve, but as there was considerable side motion or swaying of the truck, the support for the truck wheels had to be securely braced. It was also necessary to have this support adjustable longitudinally. The general plan of the extension track is shown in Fig. 20.

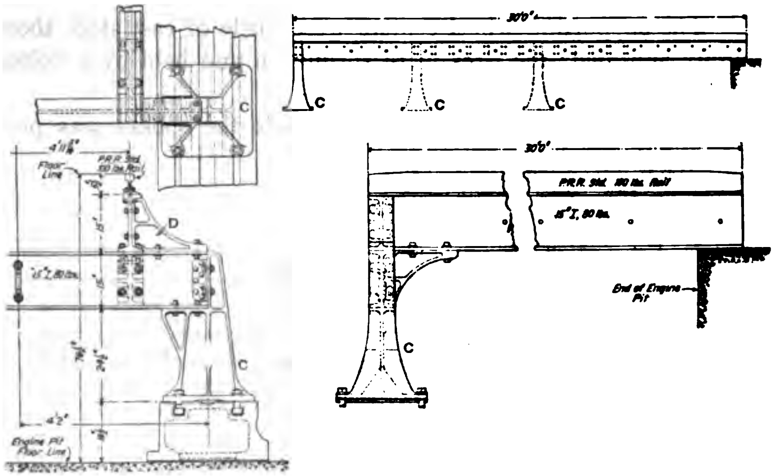


Fig. 20.—Extension Track.

The track itself consisted of two 15 in. 80 lb. I beams 30 ft. long, having standard 100 lb. rails bolted to the tops. The front end rested on a flange of the special beams shown in section at A, Fig. 21, and each side was supported by three supports marked C, (Fig. 20), at the back end and two intermediate points. These three supports, C, were bolted to the bed-plates by four bolts held in T slots. A knee brace D, was bolted to the extension track and the supports.

The extension track was prevented from spreading by T bolts in the pockets on the permanent beam A, Fig. 21, and by the knee braces on the supports. When it was necessary to move the extension track the bolts in beam A, and the knee brace bolts in all but the end supports were loosened, and the entire structure was then moved by the traveling crane.

The removable track consisted of two 15 in. 80 lb. beams 42½ ft. long, having the section shown at C in Fig 21. The end of the removable track was fastened to the permanent beam A by an angle and to the extension track by bolts with ferrules as shown in sections A B and C D.

At the supporting axles, the removable track rested on cast iron chocks E on top of the axles as shown in Fig. 22. The track was also bolted to the supporting wheel spokes. Between the supporting wheels, the track was held by screw jacks shown in Fig. 23. The jacks were also placed at the back of the pit, and the track rested on them when not in use. Several tie bars, with turn-buckles, were provided, so that the space between the two removable rails could be varied.

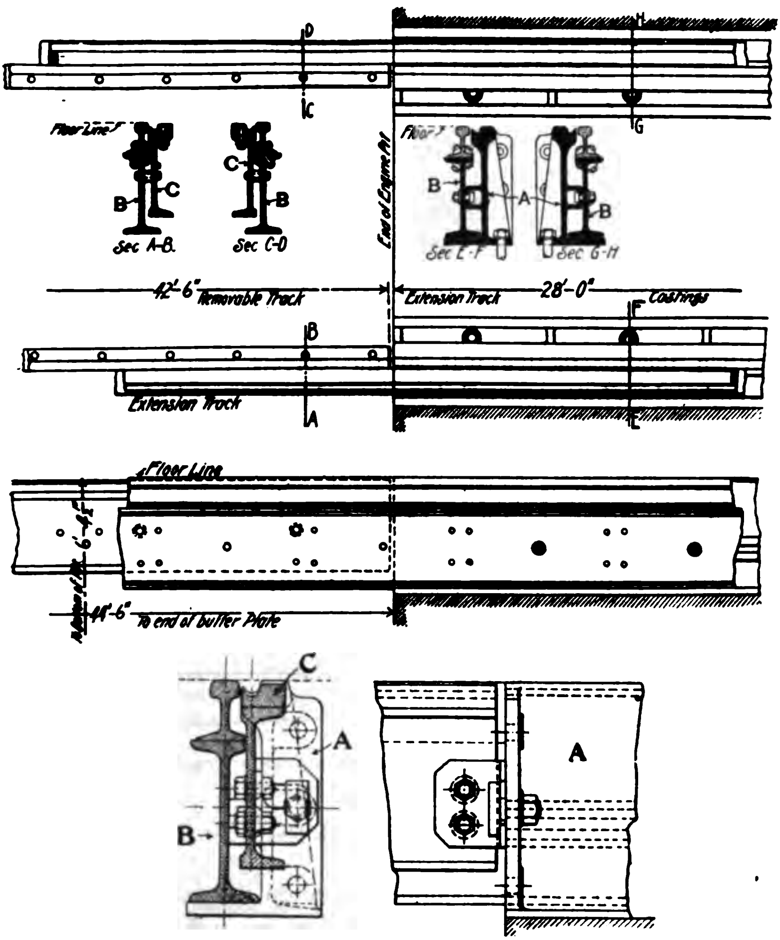


Fig. 21.—Details of Extension and Removable Tracks.

In bringing a locomotive into position on the plant, the extension track was first adjusted to support the truck. On leaving the approach track, the flanges of the wheels of the locomotive rolled in the groove in the removable track which extended out to the approach track. When passing over the extension track, however, the weight was carried by it. The groove in the removable track was designed so that the tread of the driving wheel was ¼ in. lower than the top of the supporting wheel.

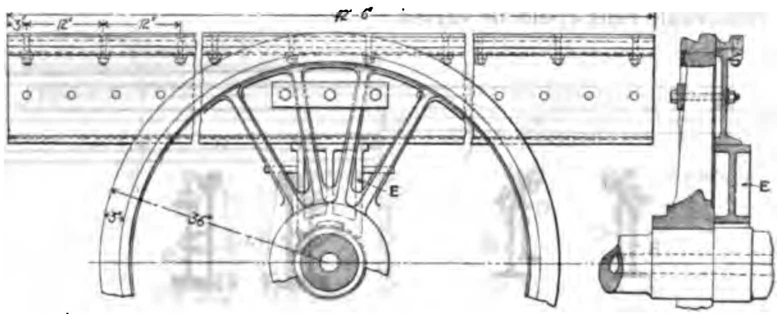


Fig. 22.—Removable Track at Supporting Wheel.

When the locomotive was in the correct position all of the weight, therefore, was off the removable track, which could then be loosened and moved to one side.

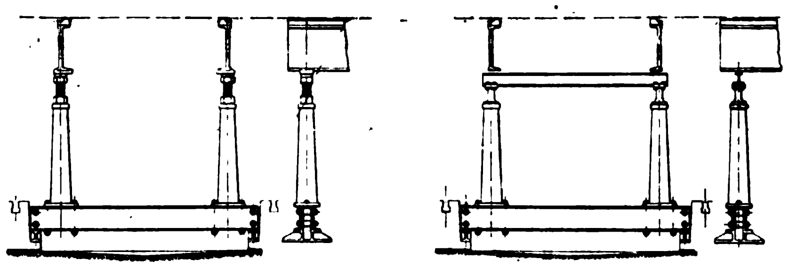


Fig. 23.—Supports for Removable Track.

ALDEN BRAKES.

The Alden absorption brakes were on the ends of each supporting shaft. This type of brake, Fig. 24, was first used as a dynamometer at the Worcester Polytechnic Institute, and is the invention of Mr. G. I. Alden, M. M. E. The brake was keyed to the axle of the supporting wheel and the brake seat was tapered. The brake was held in position on the axle by two nuts one of which was used for bringing it into place and the other for backing it off the axle.

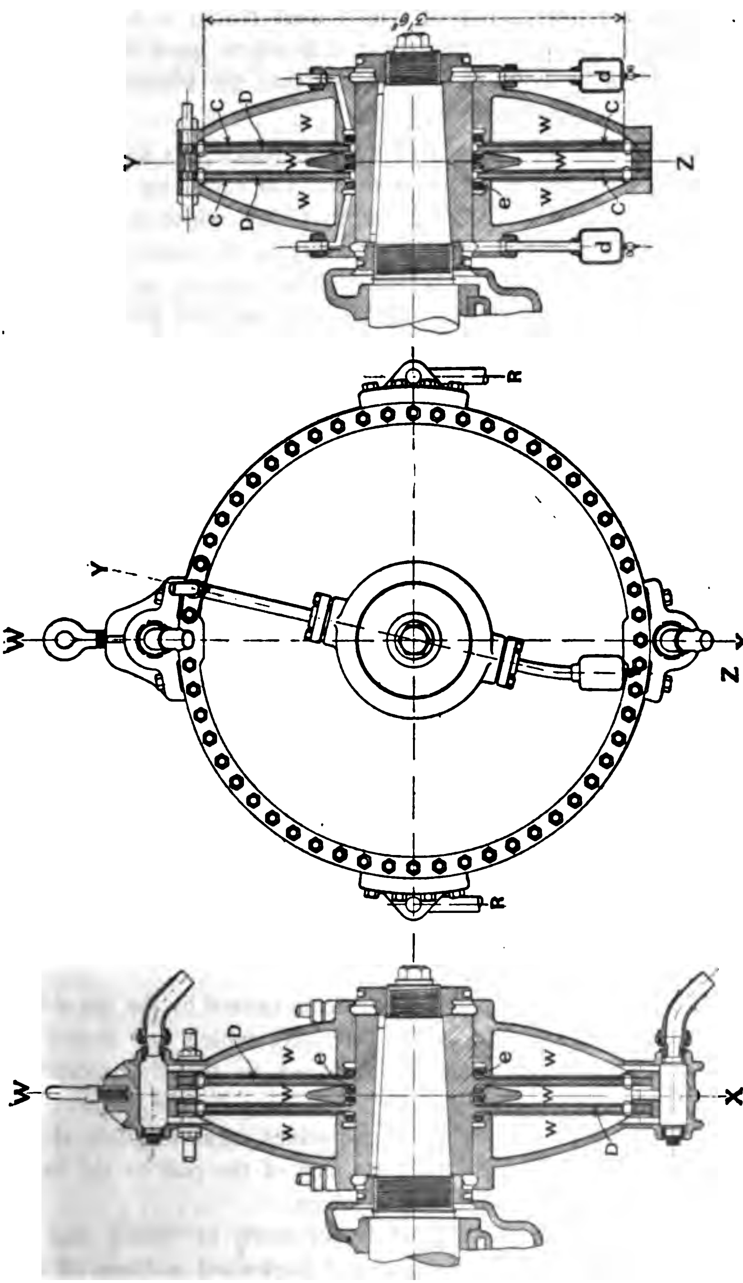


Fig. 24.—The Alden Absorption Brake.

The brake housing was kept from turning by two tie-rods marked R, the lower ends of which were bolted to brackets on the bed-plate casting. These tie-rod brackets were fastened to the bed-plates by bolts in T slots, so that the brakes could be moved to any desired position.

The discs D were a part of the hub which was keyed to the supporting axle and revolved with it. On each side of the revolving discs were copper diaphragms CCCC which were forced against the discs by the pressure of water in the spaces W. Lubrication was arranged for between these surfaces as shown in section Y-Z; the oil entered near the hub and was forced to the circumference by centrifugal action, where it escaped and was returned to the hub by exterior pipes. An oil reservoir connected to each pipe provided for leakage. The bearing surface between the hub and the housing was lubricated by oil which leaked past the packing rings (e) shown in both sections, W-X and Y-Z. This oil was caught by the drip cups (d).

Water under pressure circulated through the spaces (w w w), the effect being to press the copper plates toward the revolving discs and introduce the desired resistance to turning. The copper plates and the discs were protected from wear by the oil, the resistance being due to the viscosity of the lubricant under the imposed conditions of pressure. The heat generated was carried away by the water.

The water entered the brake at the bottom and passed out at the top as shown in section W-X, the pressure and volume being controlled by an inlet valve for each pair of brakes. Each brake had a separate outlet valve.

SAFETY BARS AND DASH-POTS.

To provide against possible accidents caused by the draw-bar breaking, two safety bars were provided, which are shown in Fig. 25. These were securely fastened to the dynamometer housings and to the regular safety bar pins on the locomotive, their length being adjusted by turn-buckles so as to allow about ¼ in. lost motion, in order that no part of the pull of the locomotive would be taken by the safety bars.

It was found necessary. while the work of testing was in progress, to dampen the forward and backward motions of the locomotive when running at high speeds, so as to protect the

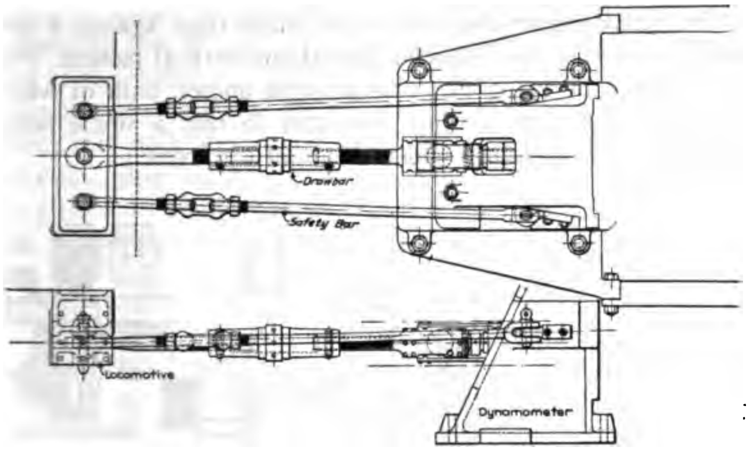


Fig. 25.—Drawbar and Safety Bars.

dynamometer from shock without interfering with the correctness of the draw-bar pull records. With that object in view, new safety bars were designed with dash-pots, as shown in Fig. 26. To accomplish the desired results it was essential that all fore and aft movement be confined to the dash-pot itself; therefore the fastenings of the safety bars to the locomotive foot plate and

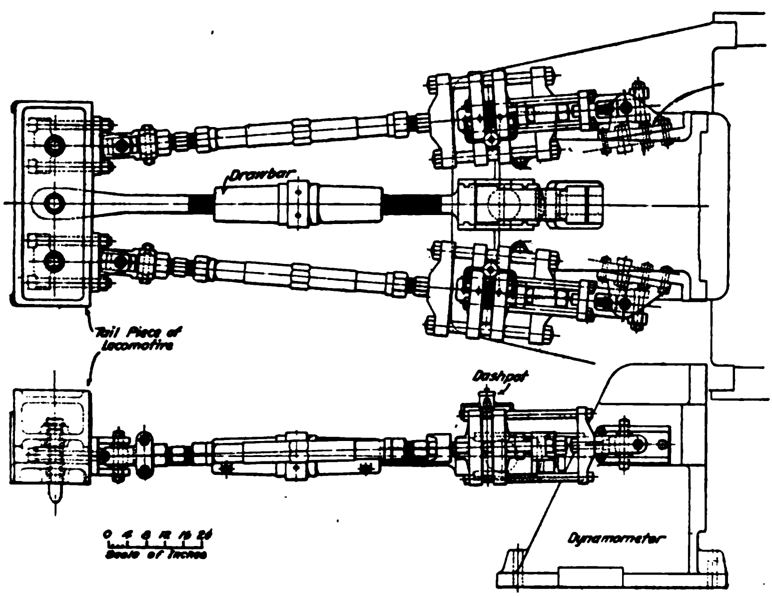


Fig. 26.—Safety Bars with Dashpots.

to the dynamometer abutments were made rigid against a fore and aft movement but allowing lateral and vertical motion. This was effected by using two pins at right angles, both of which were provided with bearings arranged so that a single screw adjusted all the bearings and took up all lost motion.

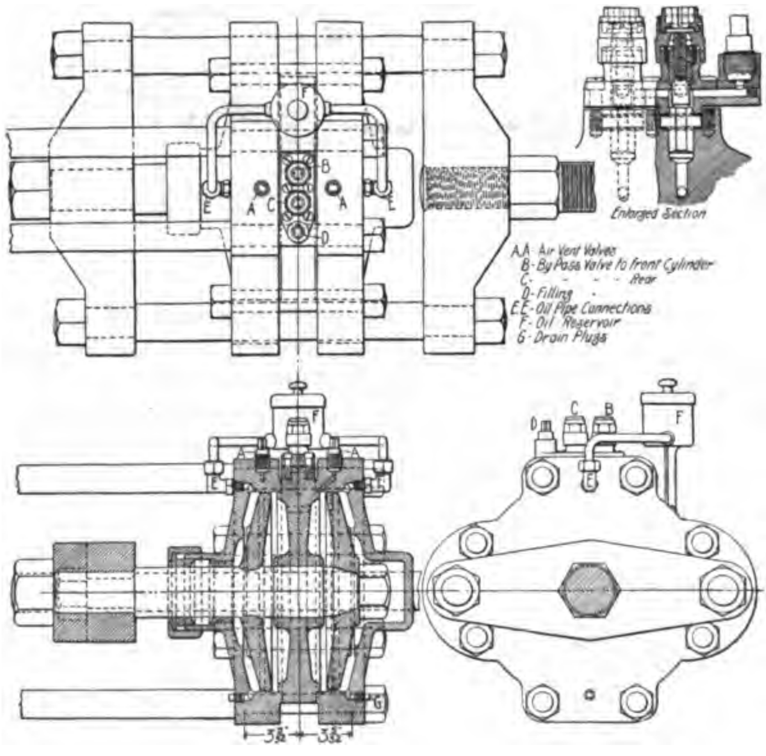


Fig. 27.—Dashpot for Safety Bar.

To provide for adjustment when the locomotive was being brought to place on the supporting wheels, the central portion of the safety bar was made in the form of a long sleeve nut with right and left hand threads.

The dash-pots are shown in Fig. 27 and consisted essentially of a cylinder, with two pistons between which was a rigid head. The dash-pot action took place entirely between these two pistons and the head. The spaces between the pistons and the outer cylinder heads were connected by piping and were therefore under no pressure. The choke plugs B and C restricted the free flow of oil between the forward and back chambers of the dash-pot. The sensitiveness of the dash-pot was also controlled by the choke plugs. Air vents at A A were opened when the dash-pots were being filled with oil. D being the filling plug for the chambers and E E for the space between the piston and cylinder heads. G G were drain plugs. The details of the choke plugs are shown.

SMOKE STACK.

The smoke stack is shown in Fig. 28. The stack was supported by gimbal rings which in turn were supported by a four-wheel truck. It was necessary to provide for a movement of the entire stack lengthwise of the plant to suit the different dimensions of locomotives tested. The method of suspension allowed for some slight variation sideways and a range of adjustment of 12 feet forward and backward. To allow the crane to pass under the stack the lower portion was made to slide up inside the stack proper, so as to leave a clear height of 21 ft. 9 in.

The telescopic portion of the stack was suspended by chains attached to the lower part. These chains passed over pulleys supported by the main stack. The telescopic stack was counterweighted as shown. The cone shaped deflector with spiral vanes at the top of the telescopic stack was intended to check the velocity of the smoke and gases, and impart a whirling motion to them, so that the sparks carried out of the locomotive stack would be deflected and caught in the large hopper. The strong draft however in some of the tests caused the sparks to be carried out of the top of the plant stack.

A door was provided for cleaning the large spark hopper, and the bottom of the hopper had a sharp slope toward one side, where there was an opening 12 inches square, with a cut-off valve. From this valve there was a pipe leading to the floor, so that when the cut-off valve was opened the sparks ran out through the pipe, to a box placed under the end of this pipe. The maximum weight caught in any one test was 1,060 pounds. The volume of the spark trap up to the top of the telescope, with the bottom of stack 16 ft. 4 in. above the rail (an average position), was about 150 cubic feet. As the cinders weighed 30 pounds to the cubic foot, this spark trap should have had a ca-

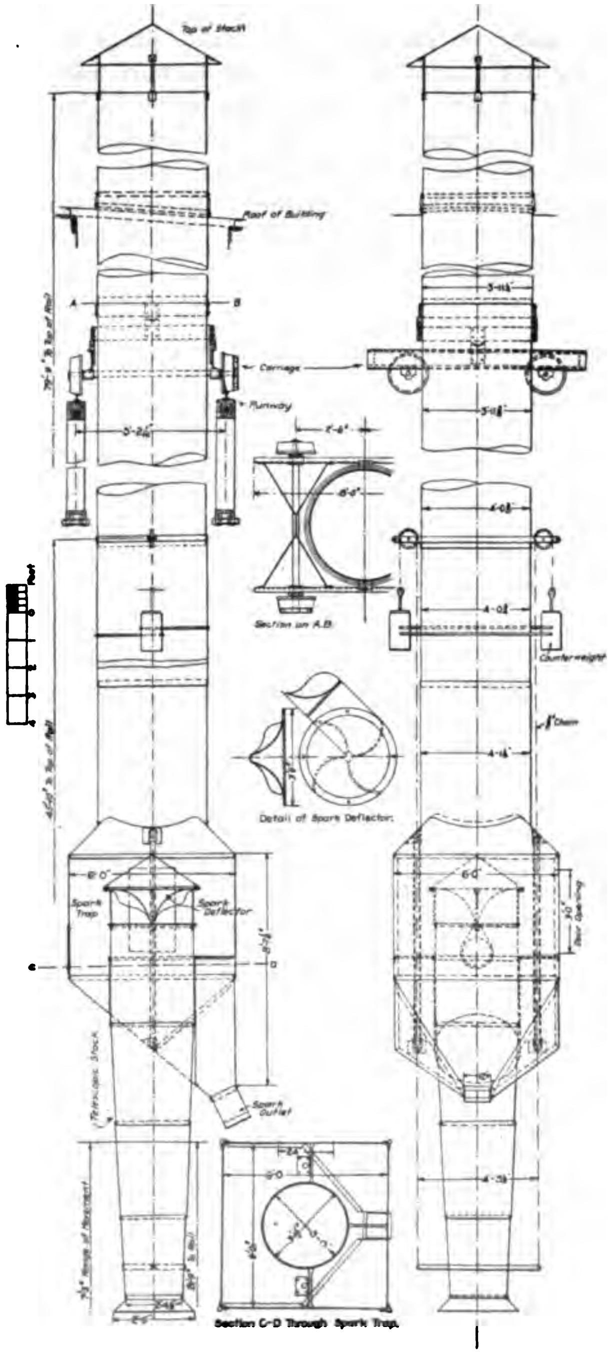


Fig. 28.—Smoke Stack.

pacity of 4,500 pounds. Notches on the side of the carrying truck wheels were used in moving the stack.

The runway for the stack was supported from the top of the main roof trusses of the building, which were 54½ feet above the floor. The opening in the roof was closed with corrugated galvanized iron sheets held down to Z bars at the edges of the opening, by clips. A walk-way was built around the stack runway to provide easy and safe access. The total weight of the stack in position was about 9,000 pounds; the total length with

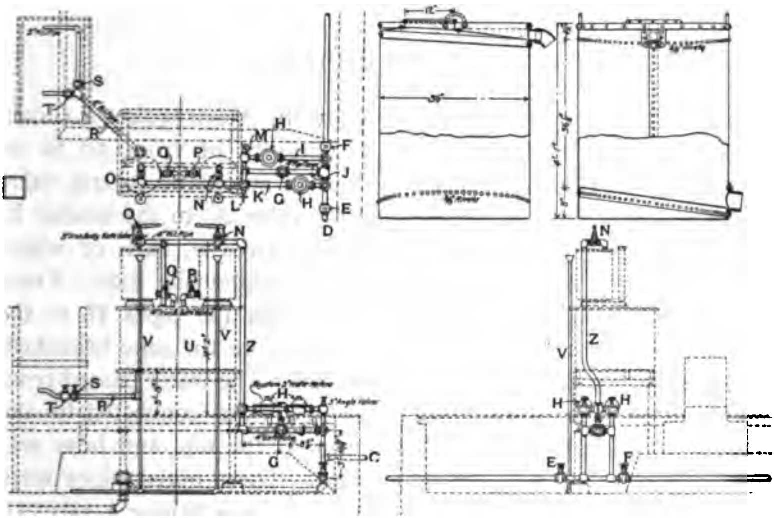


Fig. 29.—Feed Water Piping Arrangement and Water Tanks.

telescope in the lowest position was 65 feet 3 inches, the top or hood being 2 feet 6 inches high. The bottom of the plant smoke stack was never less than 16 inches above the top of the stack of the locomotive, so the draft of the locomotive was not influenced by it.

ARRANGEMENT OF WATER PIPES.

The main water supply for the boilers was controlled by the valve, F, Fig. 29. The valve, E, controlled the water supply from the Kennicott water purifying apparatus. In all but one test, however, the water supply came from the above mentioned purifier. The water passed through either one or both water meters H, or through the bypass pipe J, which was provided in case the meters were out of order. From the meters the water passed through the pipe Z to the lever gate valves N and O and thence into the weighing tanks.

From the weighing tanks the water passed through the lever gate valves P and Q, to the receiving tank U, and water which overflowed the weighing tanks was taken by the pipes VV and measured, the water thus overflowing being deducted from the meter readings. From the receiving tank the water was carried by the pipe R, to the valves S and T connecting with the tank hose of the locomotive.

BRAKE PIPING.

The arrangement of the piping for the Alden brakes is shown in Fig. 30. The water, under a pressure of from 50 to 70 pounds, passed through the pipe D to an automatic control valve B, and thence through a hand control valve A, to the header E. On this header were located the inlet valves F, each of which admitted water to a pair of brakes on a supporting axle. From the inlet valves, the water passed through the pipes H to the front of the dynamometer foundation, where the pipe branched, one branch going to each side of the plant. The water passed from the pipe to each Alden brake through hose connected to the bottom of the brake. The outlet was at the top, and hose was used for connection to the outlet pipe. These outlet pipes were led back to the bank of valves, each outlet pipe having a valve G. From the valves G the water then passed into the boshes or troughs C C and thence to the sewer.

At K was a Pickering governor driven by a driving shaft actuated by the supporting wheels. The governor controlled a pilot valve which in turn operated the automatic valve B. Owing to local conditions, this system of controlling the speed of the locomotive was not satisfactory and it was, therefore, regulated by careful manipulation of the hand control valve A. At the outlet valves G, were placed pressure gauges connected to the outlet pipes below the valve, to indicate the pressure on the brakes. The pressure in the separate brakes and the quantity of the water passing through them was adjusted by means of the inlet and outlet valves, and the speed of the locomotive kept constant by manipulating the hand control valve A, which affected all the brakes equally. Frequent adjustments of the control valve were

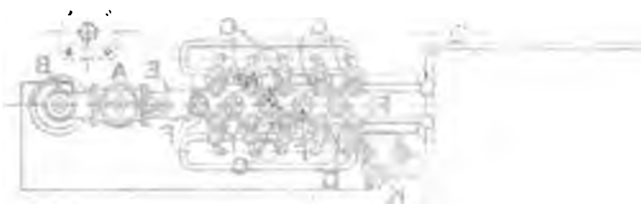


Fig. 30.

necessary, partly on account of variations in steam pressure of the boiler, but mostly on account of the sudden and violent fluctuations of water pressure.

ELECTRIC TRAVELING CRANE.

A traveling electric crane E (see Fig. 13) of 10 tons capacity, and having a span of 43 feet between centers of runways F, served the entire space occupied by the testing plant, also sufficient space beyond the pilot of the longest locomotive tested, to reach the cars loaded with supplies for the plant. The crane was used for handling the supporting wheels, axles, brakes, pedestals and other parts, when it was necessary to change their setting and also for handling all of the coal and ashes used during the tests.

CHAPTER III.

DESCRIPTION OF APPARATUS AND INSTRUMENTS.

TRACTION DYNAMOMETER.

The conditions and limitations which controlled the selection of the type of dynamometer to be constructed for the testing plant were, in part, as follows: In order that the locomotive should be held in position upon the top of the supporting wheels it was necessary that the movement permitted by the dynamometer be restricted to the smallest amount practicable, and the weighing apparatus capable of weighing either a pull or a push; should be as nearly frictionless as possible; the draw-bar height adjustable, and finally, the machine arranged so that the draw-bar pull would be shown graphically on paper as a continuous permanent record.

In fulfilling these requirements, a selection was made of the lever type of weighing apparatus in preference to either the hydraulic or the spring type, as the lever type appeared best adapted to fulfill the condition of allowing little movement to the locomotive. The Emery system of fulcrum plates was chosen to eliminate indeterminate and varying forces due to friction, as these plates were subject to simple bending and compression without the rolling action which takes place with knife edges as used in ordinary scales.

In Fig. 31 is shown the general arrangement of the dynamometer as designed and built by William Sellers & Company, Incorporated, of Philadelphia, Pa., to fulfill the above requirements.

The castings AA, together with the connecting pieces BB, formed a frame or bed-plate upon which the abutments or housings CC were supported. These housings were further con-

Fig. 31.

The Traction Dynamometer

nected by the two forged side pieces or tie-bars DD. These parts together formed the fixed or rigid framework of the machine, which was anchored to the concrete foundation by bolts. In addition to these, the projections (pp) formed dowels embedded in the foundation to prevent any sliding movement.

The maximum draw-bar pull that the dynamometer was designed to measure was 80,000 pounds. By removing the springs VV, Fig 32, and replacing them with either one of two other sets, the capacity was changed to 40,000 pounds or to 16,000 pounds as desired. In other words, with the 80,000 lbs. springs in place, the scale of the dynamometer record was 10,000 pounds per inch as measured from the datum line or line of no draw-bar pull. With the 40,000 pounds springs in place the scale was 5,000 pounds per inch and with the 16,000 pounds springs in place, 2,000 pounds per inch.

The draw-bar of the dynamometer is shown in Fig. 33. It could be elevated or depressed within a range of 12 inches to accommodate locomotives of different heights of draw-bar connection. There were two elevating screws (B), of which but one is shown. The operating mechanism for these, consisting of a worm gear, a shaft and a hand wheel, is shown in Fig. 34. The weight of the draw-bar was carried by two flexible steel plates C, of which but one is shown, and it was held in alignment by the flexible rods DD, so that its movement took place without friction. At E was a ball and socket joint which permitted slight vertical and horizontal movements of the locomotive without putting bending stresses upon the part of the draw-bar back of the ball-joint, where it had to have motion only in the direction of its length.

In Fig. 32 are shown the levers of the dynamometer, or the weighing mechanism proper. The lever system was in duplicate, i. e., levers 1, 2, on one side were repeated by 1, 2, on the other side. Instead of knife edges, as in ordinary scales, the levers had at their fulcrum points flexible steel plates which bent as the levers moved (see large detail, Fig. 32). To prevent an initial bending stress on the horizontal plate N, each of the four levers was carried on a plate M (Fig. 32) in the vertical plane. These vertical plates intersected the horizontal plates N at the center of rotation. The load, or the draw-bar pull, was transmitted from the locomotive by the draw-bar and was imposed

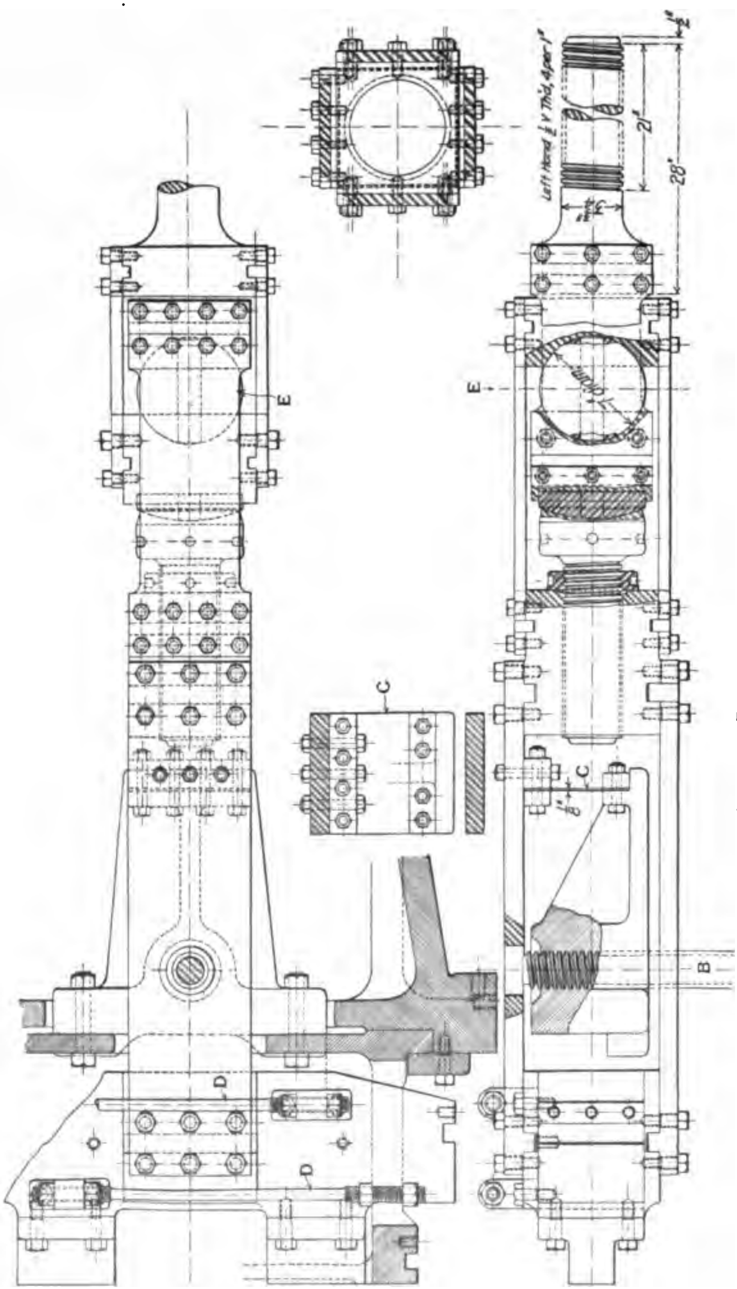


Fig. 33.—Dynamometer Drawbar.

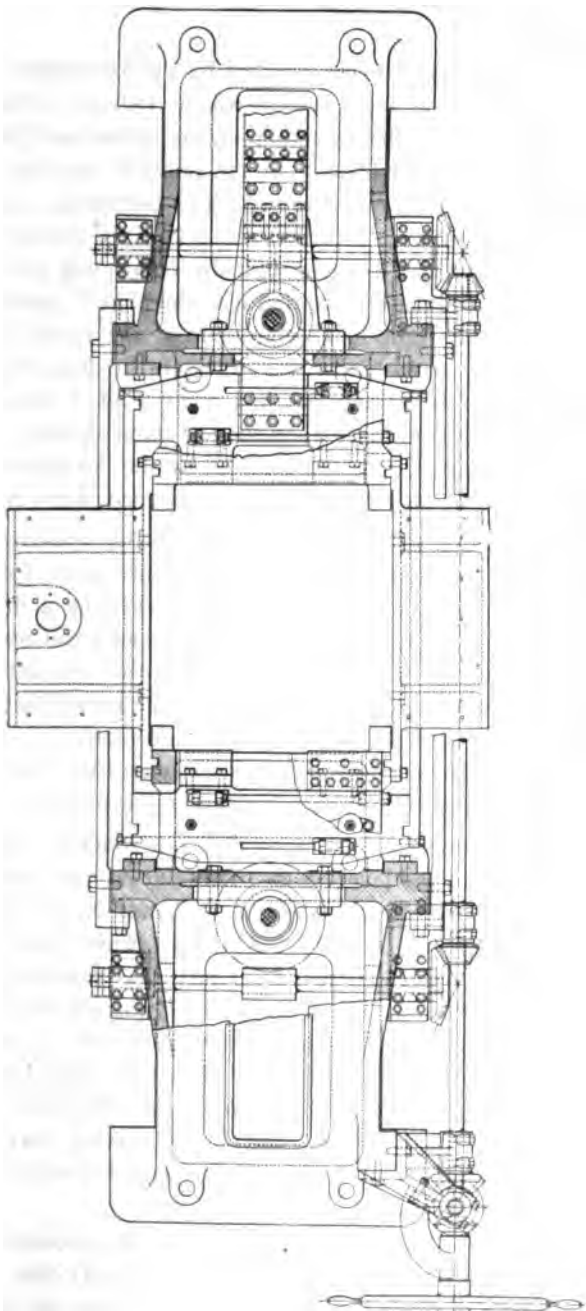


Fig. 34.—Sectional Top View of Dynamometer.

upon the lever system at E or E, according as the load was a pull or a push.

In the case of a pull being exerted by the locomotive the resulting movement in the lever system was as follows: The draw-bar moved forward in the direction of the arrow and the load came upon the left hand lever 1 at the point E, the load being brought around the levers by the yoke and becoming a push instead of a pull. This lever 1 turned about its fixed fulcrum point (f), and transmitted the load through the connecting plate Q to the lever 2, which in turn transmitted it to the plate R, until finally it came against the right hand abutment at the point T. The right hand lever 1, in this case, was quiescent or dead, but when the locomotive ran backward the left hand lever 1 became the inactive one and the load came upon the left hand surface T. The movement of the levers 2, 2 was resisted by the flat springs VV, and these formed the larger part of the resistance of the machine.

The total motion of the draw-bar due to the movements of the lever system, when under full load, did not exceed four one-hundredths of an inch, so that a locomotive exerting a draw-bar pull equal to the full capacity of the dynamometer did not move forward on the supporting wheels more than this amount. This motion was increased two hundred times at the recording pen, or for each one hundredth of an inch that the locomotive moved forward the recording pen moved through a space of two inches, the total movement being eight inches for the .04 in. movement.

Arms (OO), section A-B, extended horizontally from the lower end of each of the levers 2, 2. These arms were connected to a belt drum J, by means of thin steel bands N, so that the movement of the levers rotated the drum. This drum J was attached to a heavy tube H, which in turn was fastened to the center of the pen arm. Inside of the tube H was a torsion rod I. This rod was held so that it could not turn at the end L, and was fastened to the tube at the upper end. The tube, belt drum and pen arm were supported on ball bearings. As the tube H was turned by the movement of the levers, the torsion rod I was twisted from its upper end. This torsion rod formed the final resistance of the machine.

The end of the third lever D, to which the recording pen carriage was attached, swung in an arc and to rectify this motion a small carriage rolling in a straight runway, shown in Fig. 36,

Fig. 35.

Dynamometer Housings.

carried the pen and was attached to the third lever D by means of thin steel bands. At the opposite end of the third lever D there was a rotary dash-pot to dampen the vibrations of the dynamometer. This dash-pot is shown in detail in Fig. 37, and Vm, Vm were vanes attached to the shaft S turning in the case K. At Vf and Vf were fixed vanes attached to the case. The whole was filled with oil. While the holes (h) were open, the oil could freely pass from side to side of the moving vanes. To re-

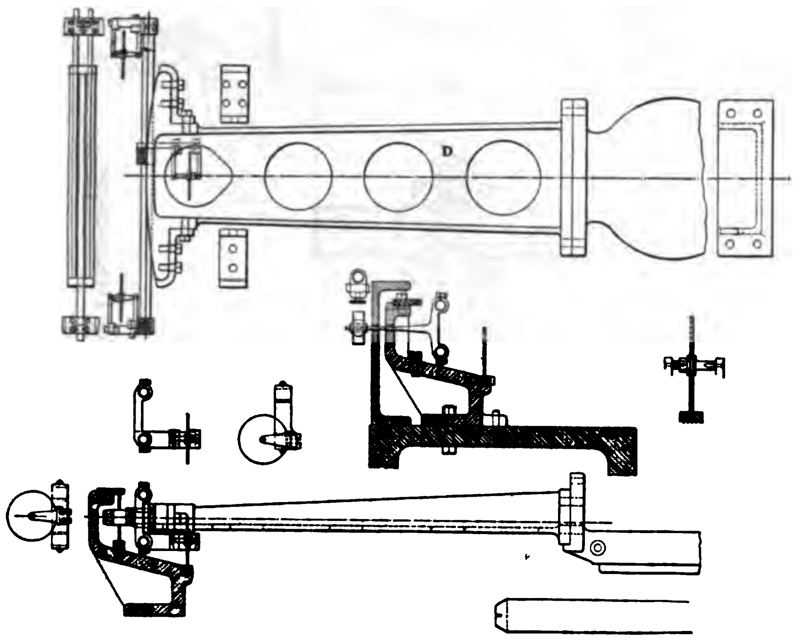


Fig. 36.—Recording Pen Arm.

strict the movement of the vanes the plug (p) was screwed down from the top (n) until it partly or wholly closed the passages (h), as desired. The dash-pot shaft was carried on ball bearings as shown.

PAPER DRIVING MECHANISM.

The plug in the right end of the main axle (see Fig. 38) had a large square groove across the face, into which a keeper was fitted. The keeper was mounted on a shaft that could be moved toward the axle so the keeper engaged in the groove. On this

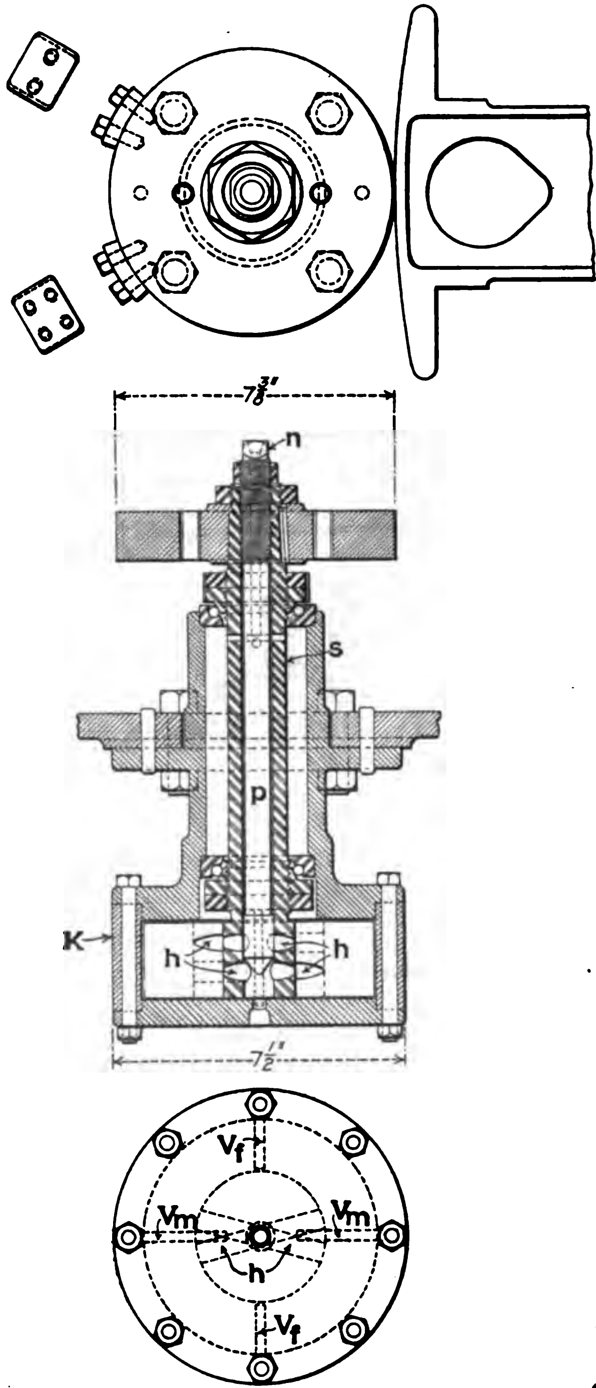


Fig. 37.—Rotary Dashpot for Dynamometer.

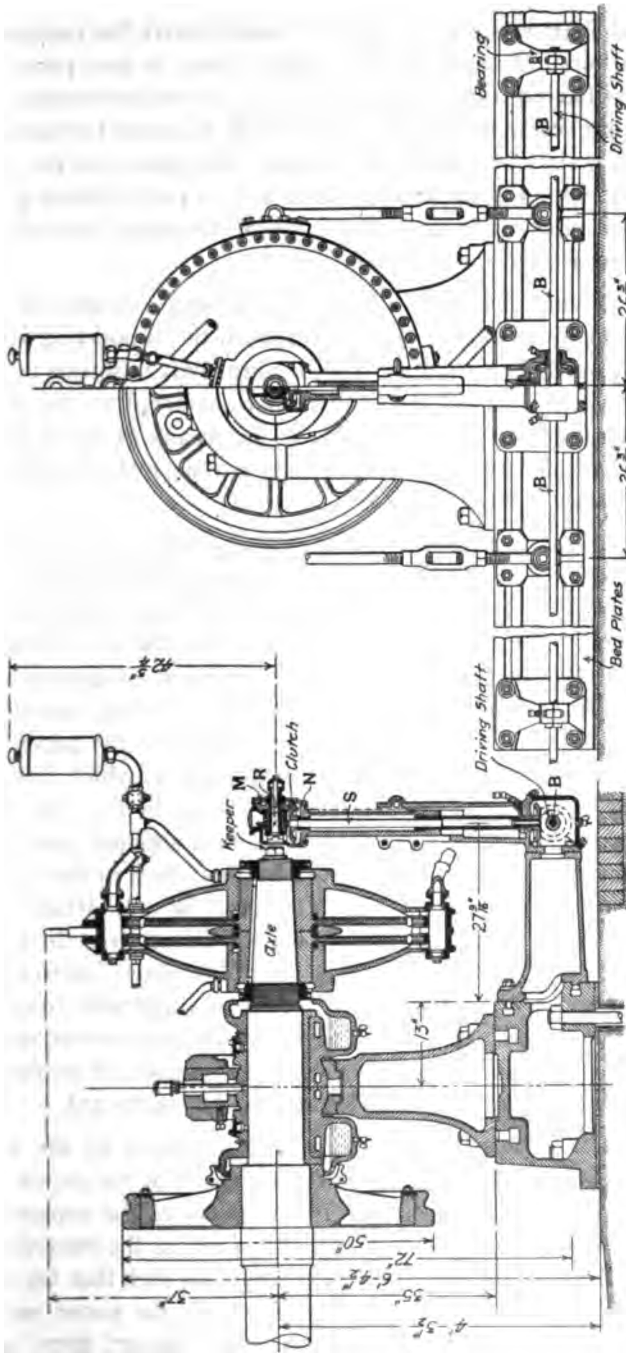


Fig. 38.—Section Showing Gear Box and Shaft for Paper Driving Mechanism.

horizontal shaft was a mitre gear M, which drove the mitre gear N, on the vertical shaft S. The shaft S was in two parts, the upper part having a key fitting in a spline in the lower part. By an elevating screw the height of the shaft R, could be varied to suit the two sizes of supporting wheels. The motion of the shaft S was transmitted to the driving shaft B, by a pair of mitre gears, and the driving shaft was supported at frequent intervals by bearings secured to the bed plates.

The driving shaft had a spline cut its entire length, so that the mechanism for taking the motion from the supporting wheel could be placed at any point. The driving shaft is shown in section at B, Fig. 39, and the motion is transferred to the paper driving shaft by the inclined shaft A, by means of bevel gears. Shaft A had also two universal joints to relieve it of all strain except a purely rotative one.

In Fig. 40 are shown the recording table and the paper driving mechanism. The roll of paper having been wound on a spare spool or drum, S, was inserted in bearings at the bottom of the frame. The paper was then carried over the idler rolls TT. and across the surface of the table. It then passed between the gripping rolls U and V and thence to the receiving spool W. The roll V was the one which gave the motion to the paper and was itself driven by means of the splined shaft X, which received its motion in turn from the shaft A, as shown in Fig. 39. The surface of the roll V was grooved to prevent slipping, and positive driving of the paper was insured by the action of the rubber roll U, which pressed against it. The spool W was driven by a friction clutch Y, which had enough tension to just keep the paper taut and not to change the speed as the roll of paper increased in size on the spool W. The spool W could be withdrawn from the machine when filled. At Z was a reversing arrangement by means of which the motion of the paper could be stopped, or continued in the same direction when the locomotive ran backward.

It will thus be seen that the paper was driven by the main supporting wheels, Fig. 38, and that the speed of the paper was proportional to the speed of the circumference of the supporting wheel, or what was the same thing, the speed of the locomotive, provided there was no slip. The gear ratio was such that for each 1,000 feet of travel of the locomotive wheels the paper moved forward 10 inches. For very slow speeds, however, there were

Fig. 39.

Cross Section, Showing Paper Driving Mechanism.

change gears for increasing the paper speed to 20 inches per 1,000 feet of travel of the locomotive.

The electric pens for recording observations are shown in Fig. 41. The pens were held in brass sleeves pivoted at the top. Over each pair of magnets was an armature attached to a shaft; on this same shaft was a vertical lever, attached by a horizontal rod to the pen sleeve. When the circuit was broken, small

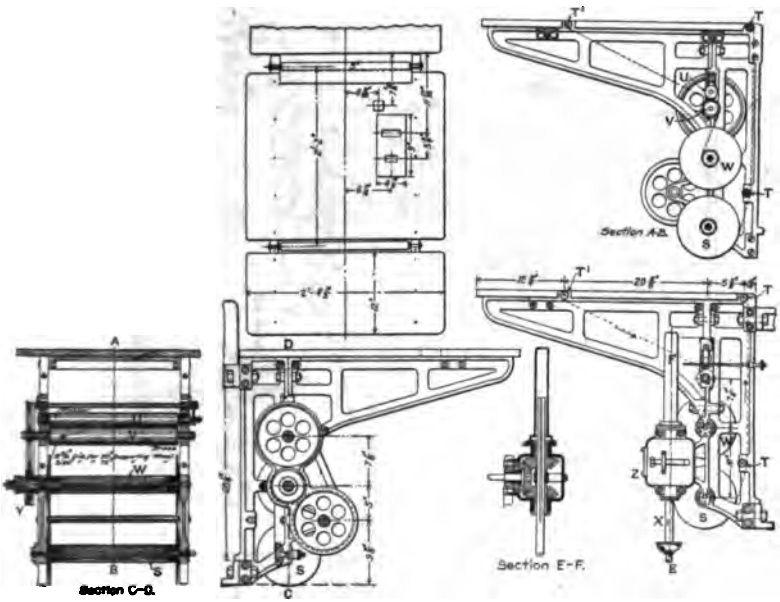


Fig. 40.—Recording Table.

springs pulled the armature up and made a jog or small offset in the line drawn by the pen on the recording paper. The usual commercial stylographic pens were used with quick drying ink. The datum line, or line of zero draw-bar pull, was drawn by the datum pen (R), Fig. 41. This instrument consisted of a small carriage having a thin roller, the surface of which was inked by a pad inclosed in the case X2. The datum pen was brought in line with the recording pen by an adjusting nut W.

At each 10 inches of length of the paper passing over the recording table, a mark was made by one of the electric pens Y, attached to the measuring roller L. This roller was exactly 10 inches in circumference and at each rotation the electric circuit

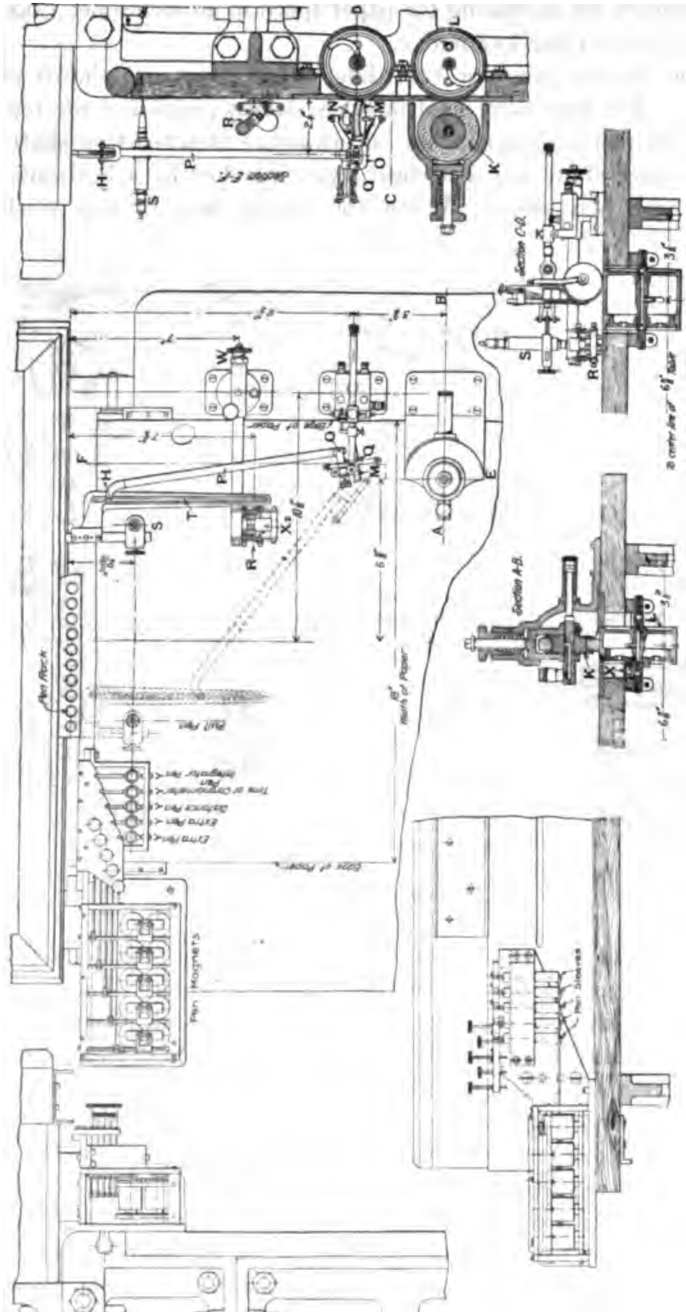


Fig. 41.—Plan and Details of Recording Table Showing Instruments.

was broken at X and a mark registered in the distance line. The rubber covered roller K above, pressed the paper against the measuring roller, the grooved surface of which prevented slipping. The chronometer pen drew the time line, showing the elapsed time in seconds.

The purpose of the integrator, Fig. 42, was to automatically measure and record the area of the surface between

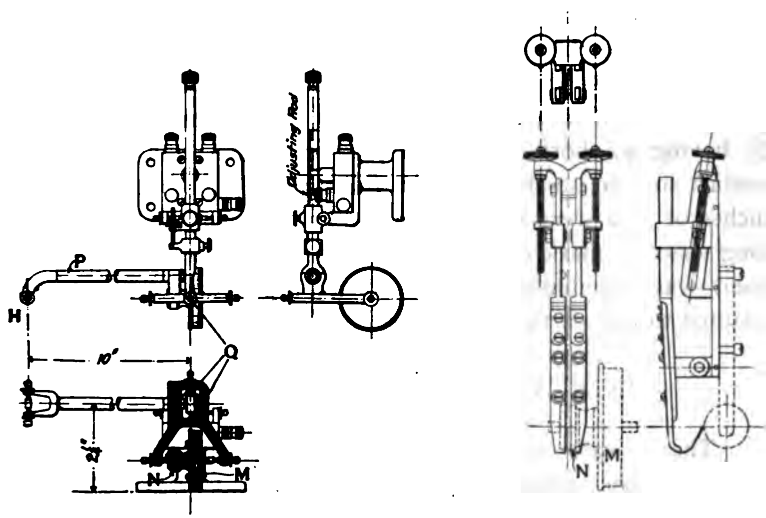


Fig. 42.—Dynamometer Diagram Integrator.

the datum line and the draw-bar pull line. This surface in square inches, divided by the length of the diagram in inches and the result multiplied by the scale of the dynamometer spring, gave the average draw-bar pull for the length of diagram under consideration. Fig. 41 shows the integrator in position on the recording taole. The integrator wheel M which was made 5 inches in circumference rested on the surface of the paper. An arm P, 10 inches long connected the integrator wheel with the traction recording pen S. The end H of the arm P swung about the fixed point Q, through an arc of 10 inches radius, guided in its motion by the slot T on the pen arm S. This slot remained parallel to the paper travel. Rotation of the wheel could occur only when the paper moved forward under the wheel.

As the integrator frame O was pivoted at Q it will be seen that as the pen S moved as a load came upon the dynamometer, the axis of the wheel M was made to take successive positions more nearly at right angles with the direction of motion of the record, and the number of turns of the wheel increased with the drawbar pull. Should the 10 in. arm have swung to a position at right angles to the paper motion, the rotation of the wheel would have corresponded with the paper travel, or for five inches travel of paper the wheel would have made one turn and recorded 5 x 10 inches, or 50 square inches area.

To record the measurement by the integrator wheel, one of the electric pens Y was connected to the instrument. The wheel M carried on its shaft a notched circuit breaker, or contact maker N, having 49 short contact surfaces or notches, and one longer contact surface, so that for each full turn of the wheel 50 square inches of area were recorded in the line and one of these was a long space to mark each 50 of these square inches. The instrument was essentially a simple form of an Amsler planimeter, adapted to this particular purpose.

INDICATOR REDUCING MOTIONS.

The indicator reducing motions used on all of the locomotives, with the single exception of the N. Y. C. & H. R. R. R. locomotive No. 3000, were the same in principle and differed only in the method of application to each locomotive.

A general arrangement of the motion as applied to the Pennsylvania H6a locomotive No. 1499, is shown in Fig. 43. A slotted lever A, took its motion from the crosshead B and in turn drove a small crosshead C, as shown in the enlarged detail. This small crosshead had attached to it the motion rod made of one inch outside diameter bicycle tube. On this tube at D and D were adjustable fingers to which the indicator drum cords were attached. As the indicators were fitted with a detent it was not necessary to make provision to detach the cord from the fingers while in motion. The blocks which slide in the slots of the lever A, were made of lignum vitæ and were frequently renewed to take up wear. At EE were bearings or supports through which the motion rod passed. The bearing proper consisted of a steel ball in a socket, free to adjust itself in alignment with the motion rod as shown in detail. The motion was adjustable in

Fig. 43.

many directions as will be noted, and the distance F could be varied by placing the crosshead pin G in any one of the four holes provided. By this means the same motion was used on engines of different lengths of stroke thus obtaining diagrams of the same length. The use of the slotted lever, as here employed, gave theoretically a correct motion or one in which the ratio of piston travel to indicator drum travel was a constant for all points of the stroke.

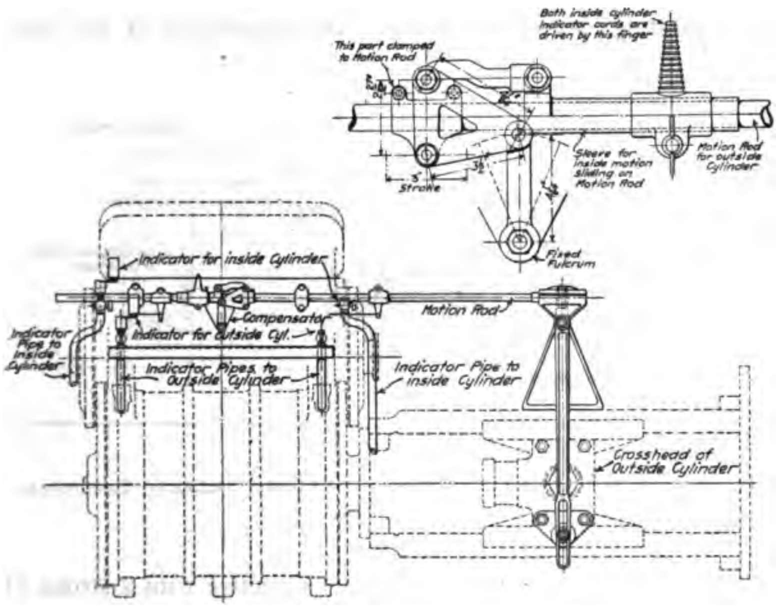


Fig. 44.—Indicator Reducing Motion with Compensator, Locomotive No. 535.

On locomotives Nos. 535 and 628 difficulty was encountered in applying a separate motion for each of the four cylinders and as a substitute for this an additional apparatus, or compensator, was attached to the motion rod of the regular reducing motion (see Fig. 44), in order to correct this motion, as given by the outside cylinder crosshead of the locomotive, so that it conformed to the motion of the inside cylinder crosshead on the same side of the locomotive. An inspection of Fig. 45 which shows the pistons, crossheads, cranks, etc., on one side of a four-cylinder balanced locomotive, makes clear the necessity for this compensating device. The two pistons reached opposite ends of their strokes at the same instant, but while the piston of the inside cylinder was at the center of its stroke the piston of the outside cylinder was not at the center of its stroke but had passed the central position by a distance A. This variation from symmetry in the motions of the two pistons with relation to each other, was due to the angularity of the connecting rod and increased as the center of the stroke was approached. It was to rectify this irregularity, and to use one motion for both cylinders, that the compensating device was made. The dimensions of the com-

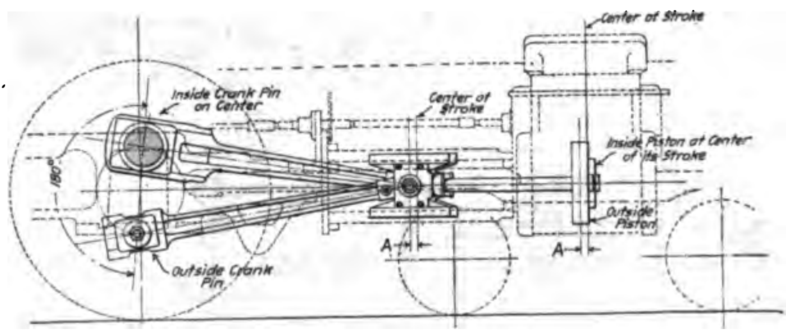


Fig. 45.— Pistons and Cranks of a Four-Cylinder Balanced Locomotive.

pensator as shown, were those for a locomotive with a stroke of 26 inches and a connecting rod length of 83 inches, for both inside and outside cylinders. The proportions of the elements of the instrument were determined graphically. This compensating device originated with Prof. W. F. M. Goss.

The distance A, Fig. 45, depends upon the relation between the length of crank and connecting rod, and in the case of locomotive No. 535 it amounted to as much as 2 inches at mid-stroke, and if not corrected would have caused an error of 8 per cent. in the mean effective pressure as obtained from the diagram.

The indicator motion as used on locomotive No. 3000 is shown in Fig. 46. There was a separate motion for each cylinder. The main lever arm was driven from the crosshead by means of a link and this lever in turn drove the motion rod.

Fig. 46.

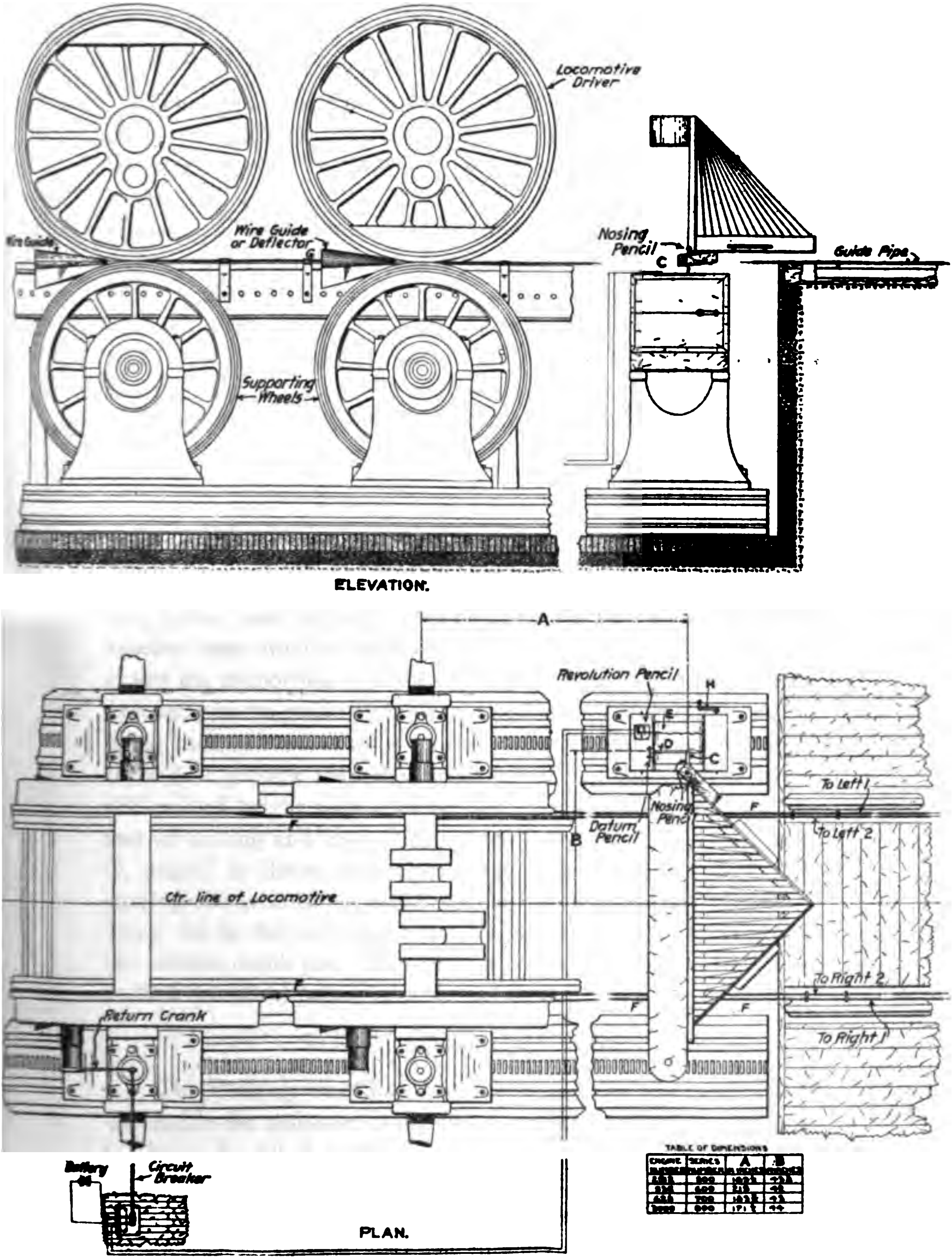


Fig. 47.—Vibration Recording Apparatus.

LATERAL VIBRATION AT PILOT.

The apparatus for obtaining the lateral vibration at pilot is shown in Fig. 47. A piece of wood was firmly bolted to the left hand corner of the pilot, carrying on the end a pencil C. Under this pencil, paper was passed to obtain a record of the motion. A datum pencil D was used to draw a reference line, and a relay magnet E moved a pencil to mark a definite point in each revolution. The right rear driving wheel was provided with a return crank which drove the revolution counter. On this shaft was located a circuit breaker set so that the circuit was momentarily broken when the side rod was in the back position. In this way the curve of movement was located with reference to the position of balance weights, etc.

COUNTERBALANCE TESTING APPARATUS.

Annealed steel wires .06 in. in diameter were run under the drivers, and measured with a micrometer caliper at intervals of five inches (see Fig. 47). Guide pipes F, 3-8 of an inch in diameter, were used to lead the wires to the point of contact between the supporting wheel and driving wheel; when curves were necessary in the guide pipes they were made of large radii. Before being used, the wires were carefully straightened, cut to a length three feet greater than the circumference of the driving wheel, and rubbed bright with emery cloth. Back of the points of contact of driving and supporting wheels were galvanized iron cones G, placed to throw the wires away from the machinery after passing the wheels. A small groove was cut across the driving wheel tire in the same plane and on the same side of the wheel as the outside crank pin. This gave a reference mark on the wires, so that the wheel positions could be located.

STEAM CALORIMETERS.

The Peabody throttling calorimeter used in all of the tests to determine the moisture in the steam at the dome and branch pipe, is shown in detail in Fig. 48. The sampling pipe, which was placed in the current of steam flowing to the throttle valve, consisted of a ½ in. wrought iron pipe with closed end and had four rows of ¼ in. drilled holes spaced spirally along the pipe. The current of steam was conducted out of the boiler through a ½ in.

pipe to a throttling nozzle or orifice at A (held in an ordinary pipe union), through which it expanded and flowed into the chamber B. This chamber B was made up of a length of 4 in. wrought iron pipe with ordinary pipe caps closing the ends. In the top was inserted a thermometer well and a connection made to a mercury column steam gauge. The whole apparatus was carefully lagged to prevent radiation.

The orifice was made as shown of hardened steel. After a number of trials of different forms of orifices, the one illustrated

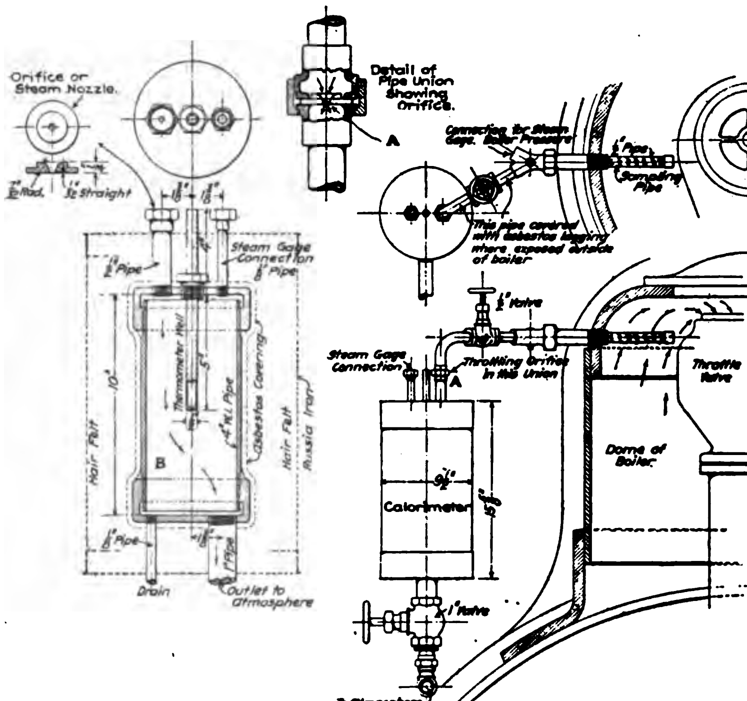


Fig. 48.—Peabody Throttling Calorimeter.

was found to give a calibrated flow of steam agreeing closely with the chosen formula. The flow through the orifice was determined by the well known approximate formula of Napier,—

$$Q = \frac{PF}{70}$$

where

Q=Flow or discharge of steam through orifice in pounds per second.

P=Boiler pressure, or pressure back of orifice, in pounds per square inch absolute.

F=Area of orifice in square inches.

The pressure into which the nozzle discharged was not of importance in affecting the flow, so long as it did not exceed 58 per cent. of the boiler pressure. The pressure in the calorimeter was usually from 2 to 3 pounds above the atmosphere.

In order that the error due to radiation from the calorimeter might be reduced to a negligible quantity, the orifice was chosen so that for the boiler pressure of the locomotive about 200 pounds of steam would flow through the calorimeter per hour. The pressure in the expansion chamber B was observed by means of a mercury column pressure gauge, reading to seven pounds and divided in tenths of a pound. The boiler pressure, or the pressure of the steam before entering the calorimeter, was observed by means of a gauge attached to the Y leading from the sampling pipe.

COAL BOXES.

The coal boxes shown in Fig. 49, of which 80 were provided, had a capacity of 19½ cubic feet and contained about 1,000 pounds of coal each. The bottom was hinged and held in place by a hasp which could be knocked out readily when the box was dumped.

WATER MEASURING TANKS.

These tanks, as shown in Fig. 29, had a capacity of about 1,500 pounds of water each, and stood on weighing scales on top of the receiving tank. The bottom of the tanks had a slope of 1 in 7 to prevent any water remaining in the tank when the discharge valve was opened. The discharge opening was 4 inches in diameter and was controlled by a lever gate valve to allow of quick opening. There was a 12 in. diameter hole in the top of the tank for receiving water, the main ending about 3 inches above the top of tank. This top opening was surrounded by a collar 2 inches high and the top of tank was a frustrum of a low cone, so that any excess water would run off, when the tank was full, through a 2½ in. hole at the lowest point.

The water supply pipe was provided with a lever gate valve, and the whole device was designed with a view to measuring a large amount of water accurately without weighing. It was thought that some of the tests would necessitate such a large consumption of water that on account of the short time available it would not be possible to weigh it, but it was found perfectly feasible to weigh all the water required.

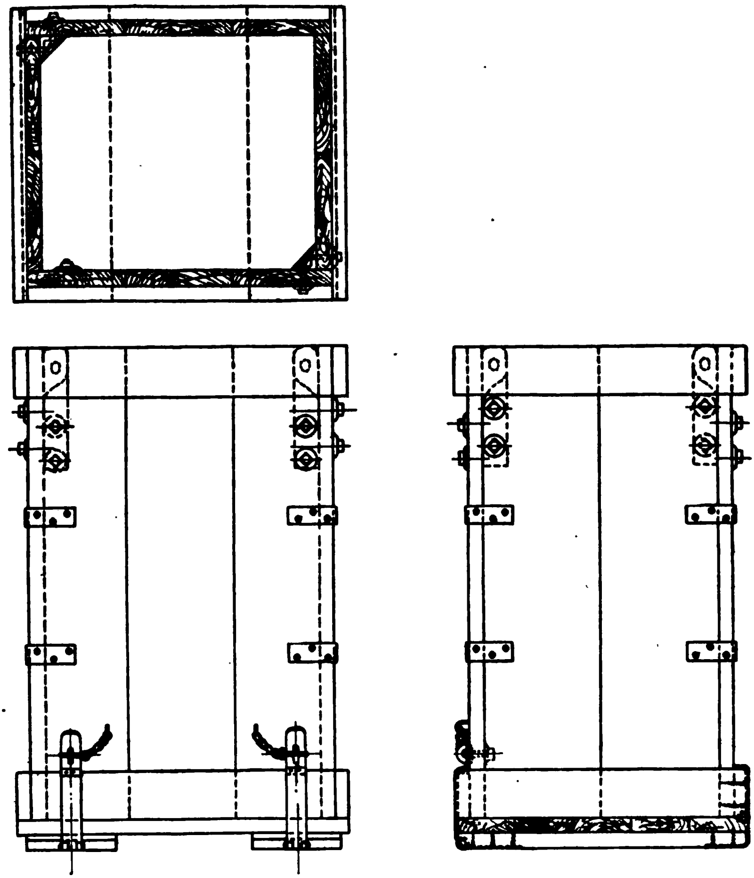


Fig. 49.—Coal Box.

LE CHATELIER THERMO COUPLES.

The thermo-couple used in the fire-box had originally a steel protecting tube and a porcelain tube outside the wires. These protecting tubes made the couple slow to respond to the increase of temperature when it was inserted in the fire-box. As firing could not be continued with the couple in place, and correct readings obtained if the fire-door was open, the time allowable for taking readings was very short. Consequently, about 6 inches of the end of the steel tube was removed, and while the changes in temperature cracked the end of the porcelain tube, so that the thermo-couple itself was exposed, the apparatus in this condition gave quick and accurate readings in half a minute—a time which did not materially interfere with the firing. Such an exposure ultimately rendered the platinum wires of the couple brittle, but they were annealed and recalibrated when necessary.

BRANCH PIPE STEAM GAUGE.

The vibrations at the front end of the locomotive made it practically impossible to maintain tight joints in the pipe leading from the branch pipe in the smoke-box to the gauge, and the fluctuations in pressure made the gauge hard to read; this gauge was, therefore, moved to the dome of the boiler, where the vibration was much less, and it was connected by a long pipe having a dip between branch pipe and gauge, so that the long column of water which collected in this pipe served to decrease the amount of the momentary variations in pressure and made it possible to read the gauge accuratelv.

CHAPTER IV.

FORMATION OF THE ADVISORY COMMITTEE.

The installation of the locomotive testing plant at St. Louis was not merely an exhibit, the main purpose being to make during the period of the Exposition, tests of different types of locomotives, from which it was hoped to secure valuable data which would be published as a contribution to the advancement of the science of locomotive engineering.

In order to enhance the value of this work it was decided to invite the co-operation of the American Society of Mechanical Engineers and the American Railway Master Mechanics' Association, to each of which the following letter was addressed:

"The Pennsylvania Railroad System has arranged with the Universal Exposition of 1904, at St. Louis, to install as a portion of its exhibit in the Department of Transportation, a locomotive laboratory, to be built upon the most approved designs, and to be operated during the seven months of the Exposition for testing locomotives.

"The entire exhibit, including the locomotive laboratory, will be in charge of Mr. F. D. Casanave, Special Agent, who is authorized to act for the Pennsylvania Railroad System in all matters pertaining thereto.

"It is the desire of the Pennsylvania Railroad System, as well as of the Exposition, that the series of tests to be conducted shall be upon the highest scientific basis, and the effort will be made to obtain results which will be of permanent value. The details of the plan have not yet been fully perfected, but it is expected that a large number of the most recent designs of American and European locomotives will be carefully and thoroughly tested.

"In order that the best results possible may be attained, it has been decided to ask your honorable body to appoint an Advisory Committee of three members. The Pennsylvania Railroad

System will provide all necessary apparatus and the force of engineers necessary to conduct the tests. It is desired that the Advisory Committee shall assist in laying out the program of tests, and in making the plans that are necessary to secure the most important and most reliable results. You are requested to appoint such a committee, and to appoint men who will be able and willing to give the necessary time and study to the subject. It is important that the plans should be effected at the earliest date possible in order to secure the hearty and full co-operation of the railroad companies and the locomotive builders, both in this country and in Europe.

"It is our intention to ask the General Commissioners of the principal European countries to appoint each a mechanical engineer of high standing to represent those countries on the Advisory Committee.

"For the Pennsylvania Railroad System: J. J. Turner, Third Vice-President, Pennsylvania Lines West of Pittsburgh.

"Theo. N. Ely, Chief of Motive Power, Pennsylvania Railroad System.

"For the Universal Exposition, St. Louis, 1904: Willard A. Smith, Chief, Department of Transportation Exhibits, Louisiana Purchase Exposition."

Having received this communication, the American Railway Master Mechanics' Association, after discussion expressing the appreciation of members of the importance of the plans thus outlined, adopted the following resolutions:

"Whereas, this Association has been informed by the Pennsylvania Railroad Company that it will erect at the World's Fair, St. Louis, 1904, a complete laboratory for the testing of locomotives, at which it contemplates making full tests of locomotives of various types, as well as special appliances pertaining to locomotives; and

"Whereas, the Pennsylvania Railroad Company has invited this Association to appoint three of its members to advise and consult in the carrying out of this project; be it

"Resolved, That the President of this Association be authorized to appoint, after conference with the Pennsylvania Railroad Company, three members of this Association to act as an Advisory Committee to the Pennsylvania Railroad Company, in matters relating to the testing of locomotives at the laboratory, which that

Company is to install in the Transportation Building of the Louisiana Purchase Exposition, St. Louis, during the seven months from May 1st to December 1st, 1904; and be it further

"Resolved, That the thanks of this Association be tendered to the Pennsylvania Railroad Company for giving the members of this Association the opportunity of participating in the investigations outlined in the preceding resolutions."

Similar action was taken by the American Society of Mechanical Engineers.

Committees were appointed in accordance with these resolutions, as follows:

By the American Society of Mechanical Engineers: Messrs. W. F. M. Goss, Edwin M. Herr and J. E. Sague.

By the American Railway Master Mechanics' Association: Messrs. F. H. Clark, H. H. Vaughan and C. H. Quereau.

This favorable action of the two associations resulted in adding to the experts to be provided by the Pennsylvania Railroad System, men eminent in their respective professions and distinguished by their well known learning and experience in the fields of theoretical and practical science.

At a formal meeting of the Advisory Committee an organization was effected by the election of Prof. W. F. M. Goss, Chairman, and Mr. H. H. Vaughan, Secretary. After considering certain details entering into the work of the Committee, the Chairman was appointed a committee of one to outline a detailed program governing the tests.

Subsequently, it was deemed advisable to secure additions to the organization already described and with that object in view the Special Agent addressed letters to the Baldwin Locomotive Works, the American Locomotive Company and the Rogers Locomotive Works, inviting their co-operation and the appointment of representatives to the Committee already named, which representatives would be known as Affiliated Members and be given equal voice and vote in the work and deliberations of the Advisory Committee. The Baldwin Locomotive Works appointed Mr. H. V. Wille, their Assistant Superintendent, the American Locomotive Company having their Vice-President, Mr. Sague, on the Committee appointed by the American Society of Mechanical Engineers, made no other nomination. The Rogers Locomotive Works did not avail themselves of the opportunity.

Letters of similar import were also addressed to the Commissioner General for Great Britain, Col. Charles M. Watson; to the Imperial Commissioner General for Germany, Dr. Theodore Lewald; and to the Commissioner General for France, M. Michel Lagrave, extending an invitation to co-operate in this work and to name a representative to act with the Committee in the capacity of Affiliated Member.

Mr. Karl Steinbiss, Director, Royal Prussian Railway, and Mr. John A. F. Aspinall, General Manager, Lancashire & Yorkshire Railroad, were nominated by the respective Commissioners General of Germany and England.

No nomination was made by the Commissioner General of France.

At this juncture the Pennsylvania Railroad System also announced their appointments and the completed organization is given on page 1.

CHAPTER V.

OPERATING FORCE.

The majority of the observers comprising the force were supplied by the Pennsylvania Railroad System, but a number were provided by some of the members of the Advisory Committee, and served on the force for longer or shorter periods.

POSITIONS ON THE FORCE.

The positions on the force were as follows:

Director of Tests	1
Assistant Director of Tests	1
Foreman of Plant	1
" " Tests	1
Editor	1
Stenographer	1
Chemist	1
Computers	3
Brake Wheel Operator	1
Dynamometer Observer	1
Cab Observer	1
Speed and Draft Gage Observer	1
Brake and Revolution Counter Observer	1
Coal Observer	1
Pyrometer Observer	1
Calorimeter Observer	1
Water Observers	2
Indicator Observers	2
Draftsmen	2
Machinist	1
Boilermaker	1
Engineman	1
Firemen	2

Craneman	1
Oilers	2
Wipers	3
Watchman	1
Total	36

The positions requiring the most experience were filled by a permanent organization which remained unchanged throughout the entire time; this left ten positions as observers, which were filled by men who were connected with the work for about two months each. The first week after a new observer arrived was spent on the work which he was to take up, under the direction of the man who was about to leave.

All of the observers had had shop experience; a majority had also had a technical education, and were, for the most part, what are commonly known as Special Apprentices.

There were three objects to be attained:

1st. The proper running of plant and locomotive.

2nd. The taking and recording of observations.

3rd. The computing of the data.

The first was under the immediate charge of the Foreman of Plant, the second under the Foreman of Tests and the third under the Assistant Director of Tests.

The number of men under each Foreman differed with the conditions; when tests were going on and all parts running smoothly, the Foreman of Plant would have charge of the oilers and wipers, but when trouble occurred, necessitating repairs of some kind, practically the entire force devoted their attention to the repairs.

Particular attention was paid to the selection of firemen, the best firemen on the divisions using a similar quality of coal to that used for the tests, being chosen. These firemen were then tried on the actual work at St. Louis and the best two retained.

Some of the owners of locomotives provided firemen and these, in a few instances, fired intermediate tests, i. e., one coming between a heavier and a lighter test, at the same speed. This was done to detect differences in skill of firing, as affecting the results; for any marked departure in an intermediate test would at once be apparent.

The total number of persons connected with the force at St. Louis is given in the following table:

Permanent organization (not including laborers)	19
Observers, serving about two months each	41
Enginemen and firemen	7
Oilers, wipers and watchman	12
Representatives of other roads	18
Persons temporarily a part of force	14
	111

The total number of individuals forming the force at any one time did not exceed 40, and only attained that number because the time of the observers overlapped, so that those who were to leave could train the new men to their duties.

CHAPTER VI.

PLAN AND SCOPE OF TESTS.

It was originally intended to make from sixteen to twenty tests with each locomotive. The conditions under which they were to be made are shown by the diagrams (Figs. 50 and 51), in which tests 1 to 4 represent a series at constant cut-off and varying speeds; tests 5 to 8 a series at a longer cut-off—the exact point of cut-off to be determined by the limit of boiler capacity at 320 r. p. m. The cut-off in tests 9, 10 and 11 was to be determined by the limit of the boiler capacity as shown by test 9.

Test 12 was to establish the limit of boiler capacity at 160 r. p. m., and if the adhesion would permit, tests 13 and 14 were also to be made.

Tests 15, 16, 17, 18 and 19 were to be throttling tests, all at one speed, to determine the influence of throttling on steam economy.

Tests 20, 21 and 22 were to be under starting conditions, at very long cut-offs, with the power of the locomotive reduced by throttling, to avoid slipping the wheels.

Compound locomotives were to be tested under conditions corresponding to the plans outlined above, but modified, if necessary, to suit the peculiarities of construction.

It will be apparent that tests under these conditions cover the entire range of operation of the locomotive, at least with an open throttle. At any particular speed an attempt to use a longer cut-off than any shown, would result in a failure of the boiler to supply sufficient steam or at low speed would cause slipping of the driving wheels, while at a limiting cut-off an attempt to increase the speed would result in failure of the boiler to supply steam.

But this scheme of tests had to be somewhat modified by limitations of the plant and of time.

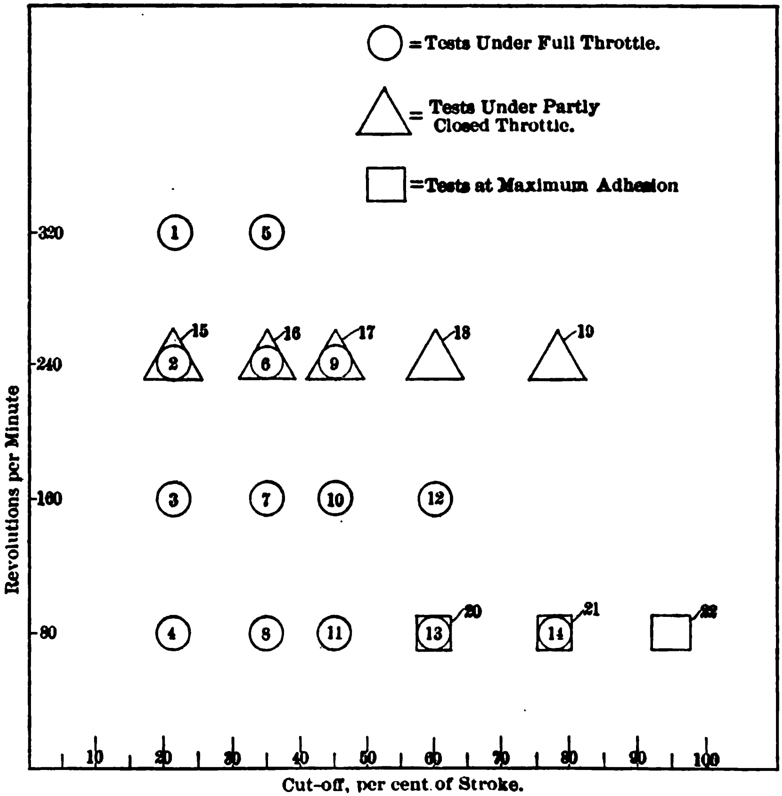


Fig. 50.—Schedule of Tests, Passenger Locomotives.

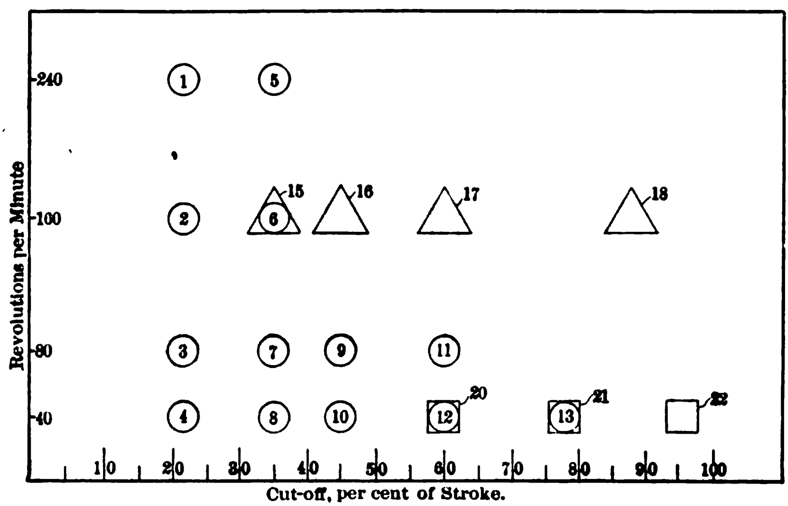


Fig. 51.—Schedule of Tests, Freight Locomotives.

The adhesion of the driving wheels to the supporting wheels proved to be less than anticipated, and the forward and backward motion of the locomotive at high speeds on account of the rapidity of the blows transmitted to the dynamometer and the inertia of the parts of the dynamometer did not permit proper readings to be given under these conditions.

It will be seen that tests 13, 14, 20, 21 and 22 were all to be run at the very limit of adhesion, but as unfortunately the water pressure which provided the braking power varied suddenly and between wide limits, it is clear that under such conditions it was best to omit these tests.

As the dash-pots could not be obtained until all of the freight locomotive tests were finished, tests 1 and 5 had to be omitted.

On the first three locomotives, throttling tests were made, but as all the subsequent locomotives, as well as the third, were compounds, it was felt that the limited time could be better utilized in getting the regular tests with as many locomotives as possible, rather than obtaining the full number of tests on each one of a smaller number.

All the compounds but the De Glehn and Hanover locomotives, were constructed so that the cut-off in both high- and low-pressure cylinders was practically the same.

The Hanover locomotive had one reversing screw, but was designed to have about 20 per cent. longer cut-off in the low-pressure cylinder than in the high-pressure. An average of the tests shows that there was an actual difference of 17½ per cent. in the cut-offs of the two cylinders.

The De Glehn had two reversing screws, and the cut-off in the high- and low-pressure cylinders could be varied independently. The difference in cut-off varied from 20 to 28 per cent., the average difference being 24½ per cent.

No tests were made of compounds with high-pressure steam in the low-pressure cylinder, or "working simple," as the low adhesion made it impossible to run such tests.

CHAPTER VII.

CALIBRATION OF INSTRUMENTS.

INDICATORS.

An approved type of inside spring steam engine indicator was selected. Indicator springs were tested on a steam drum with an automatic dead weight valve, in which the volume of steam remained practically constant, and the pressure was varied by changing the weights on the valve. Each spring was tested, and the errors noted both for ascending and descending pressures at intervals of ten pounds through the range of the spring. These calibrations were repeated after each eight locomotive tests.

When the steam was kept in the indicator all the time the spring became hot, which made necessary a material correction in the scale of spring, but as in the actual service in the tests, the steam was only admitted to the indicators every ten minutes, the same plan was tried in testing the springs and then they were found to have very little error and did not show marked changes.

All indicators were tested for parallelism of pencil movement, by removing the spring and pushing the pencil to the top of card and allowing it to fall, at several points on the circumference of the drum. The perpendicularity of these vertical lines to the longitudinal line drawn by revolving the drum with the pencil motion in its lowest position, and the parallelism of the vertical lines to each other showed the correctness of the parallelism of the pencil movement. The parallelism of the piston movement to the drum axis with the spring in place was determined by verifying the angle between the atmospheric line and a steam line made with the drum at rest.

By the use of a device similar to the Brown drum spring testing device, diagrams for various tensions of drum springs were obtained, and diagrams of the drum spring tension for each indicator were taken and the tension adjusted to give the best results at the speed at which the test was run.

The influence of the inertia of the moving parts of indicators was ascertained by taking cards at very slow speeds, and others at the highest speed which was attained; the difference in length of card showed the influence of inertia.

The ordinary valve oil, which had some solid mixed with it, did not give very good results in lubricating the indicator pistons, the cards giving evidence of the piston sticking, and the grooves in the piston were found filled with a hard reddish brown substance; when a valve oil that had been twice filtered was obtained, the cards improved.

While the indicator supports were thought to be sufficiently rigid to start with, it was found that making them as stiff as possible by using additional braces, improved the appearance of the cards.

STEAM GAUGES.

All steam gauges were frequently tested at intervals of ten pounds on a dead weight gauge tester, and errors noted both for increasing and decreasing pressures. The recording steam gauge was tested in the same way; no readings being taken unless piston of tester was revolving.

STEAM CALORIMETERS.

A design of throttling-calorimeter, which had been approved by Prof. Peabody, and which was essentially a Peabody calorimeter, was made, and three calorimeters were manufactured on this design. The calorimeters were tested to a water pressure of four hundred pounds, and made tight at that pressure.

Removable orifices were provided, which delivered about two hundred pounds of steam per hour; the diameters of the orifices being appropriate for pressures ranging from 80 to 250 pounds. The deliveries of these orifices were carefully calibrated by a coil condenser; all the steam passing through the calorimeter being condensed and weighed.

The calorimeters were lagged with an asbestos cover, 2½ inches of hair felt and a casing of Russia iron outside of the hair felt.

No correction was made for radiation from the calorimeter.

WEIGHING SCALES.

Standard test weights were provided with which all scales were tested at intervals of one month, or oftener, when the results indicated the necessity for more frequent tests.

WATER METERS.

Both water meters were tested by passing water through them, and weighing the water, and observing the temperature. Tests were made at rates of flow varying from 3 to 15 cubic feet per minute, both for intermittent and continuous flows. The correction factor determined from these tests, for the average rate of flow during the test, was used in comparing the results of metering and weighing the feed water.

PYROMETER.

The pyrometers for measuring fire-box and smoke-box temperatures consisted of thermo couples, each couple being composed of a junction of platinum with platinum-rhodium wire, forming the Pyrometer Le Chatelier.

The temperature reading was obtained by means of a millivoltmeter showing the electromotive force set up in the thermo couple, when heat was applied. The couples and millivoltmeter were compared with the Official Standards of the Bureau of Standards at Washington, D. C., and all temperature readings were corrected by reference to their certificate.

THERMOMETERS.

Thermometers were provided as follows:

Six	reading	from	0	to	212	F.	for	feed water.
Ten	"	"	0	"	400	F.	"	calorimeters.
Six	"	"	0	"	600	F.	"	"
Four	"	"	0	"	550	C.	"	smoke-box.

Of these thermometers, two of each kind were calibrated at a number of points throughout their respective ranges, by the Bureau of Standards, Washington, D. C., and these certified thermometers were used as standards for the determination of the errors of all other thermometers used.

BAROMETER.

For observation of the atmospheric pressure, a mercurial barometer was used. This instrument was calibrated by the Bureau of Standards, Washington, D. C., and a curve of true pressure was plotted which was used to correct all readings.

DRAFT GAUGES.

"U" tube gauges containing water were used to obtain the smoke-box, fire-box and ash pan pressures. These gauges were tested by the Bureau of Standards, Washington, D. C., for accuracy of graduation of scales and uniformity of bore of tubes. These corrections have been plotted and were applied to all readings.

To measure the lower pressures in the calorimeters single tube mercury pressure gauges were used. These gauges had a range from 0 to 7 pounds per square inch and were tested by the Bureau of Standards at Washington, D. C., for accuracy of scale readings and uniformity of bore of tube, and the plotted curve of these tests was used to correct all readings.

COAL CALORIMETERS.

The coal calorimeter used was the William Thompson calorimeter with some slight modifications to facilitate working and output. This calorimeter was standardized by testing in it two samples of coal which were previously tested in ten different Bomb Calorimeters, including a test in the Bomb Calorimeter at the Bureau of Standards, Washington, D. C. The mean of these ten determinations was taken as representing the heat units in these two coals, and these coals when tested in the Thompson Calorimeter, enabled it to be standardized so as to give results the same as the Bomb Calorimeter. Furthermore, a sufficient amount of these two coals was prepared so that the Thompson Calorimeter was frequently checked. It also provided a means of ready standardization, in case of accident to any of the parts of the Thompson Calorimeter, or in case of getting a new instrument complete.

ORSAT APPARATUS FOR ANALYSIS OF SMOKE-BOX GASES.

The Orsat apparatus used in analyzing the smoke-box gases had its measuring pipette carefully calibrated by filling with water at room temperature, and then weighing this water as a whole and in successive portions corresponding to the graduations on the measuring pipette. The necessary corrections, where any where found requisite, were used in reading the percentages from the measuring pipette.

CHAPTER VIII.

METHODS OF RECORDING TESTS.

The rules prescribed for the government of the tests and the methods followed in obtaining the original data as well as the calculated results, are here given in considerable detail. A list of items comprising the observed and calculated results obtained are given below:

DESCRIPTION, DIMENSIONS AND PROPORTIONS.

DRIVING WHEELS.

1.	Number of pairs						....
2.	Approximate diameter, inches						....
3.	Measured circumference,	feet,	Right	No.		1	....
4.	"	"	"	"	"	2	....
5.	"	"	"	"	"	3	....
6.	"	"	"	"	"	4	....
7.	"	"	"	"	"	5	....
8.	"	"	"	Left	"	1	....
9.	"	"	"	"	"	2	....
10.	"	"	"	"	"	3	....
11.	"	"	"	"	"	4	....
12.	"	"	"	"	"	5	....
13.	Average	"	"				....

The circumference of the driving wheels was measured with a flexible steel tape, divided in feet, and hundredths of a foot. The circumference was taken at the point where the driver rested on the rail. Assuming the gauge of track as 4 feet 8½ inches and the width of the rail head as 2¼ inches, the distance between the circumferences measured, 4 feet 10¾ inches.

ENGINE TRUCK WHEELS.

14. Number ....
15. Diameter, inches ....

TRAILING WHEELS.

16. Diameter, inches ....

WHEEL BASE.

17. Driving wheel base, in feet..........................
18. Total wheel base, in feet............................
19. Gauge of wheels, in inches...........................

WEIGHT OF ENGINE, POUNDS.

(*With water at second gauge cock and normal fire.*)

20. On truck ....
21. " first drivers.................................
22. " second " ....
23. " third " ....
24. " fourth " ....
25. " fifth " ....
26. " trailers ....
27. Total ....
28. Total on drivers ....

As there was no scale at St. Louis with sufficient capacity to weigh many of the locomotives which were tested, the locomotive was weighed at the most convenient point by a member of the testing force, although in some cases it was necessary to take the builders' weights of the locomotive in working order.

CYLINDERS.

29. High pressure, number...............................
30. Low " " ....
31. Arrangement ....
32. Diameter, inches, high pressure, right...................
33. " " " " left ....
34. " " low " right...................
35. " " " " left ....

The diameters were taken with an inside micrometer caliper, at the head end, crank end and middle of the bore of the cylinder. These three locations in the cylinder were measured with the calipers in a vertical position, and also in a horizontal position; the diameter given being an average of the six measurements obtained in this manner.

STROKE OF PISTON, FEET.

36.	High	pressure,	right	....
37.	"	"	left	....
38.	Low	"	right	....
39.	"	"	left	....

The locomotive being set on one of its dead centers, the distance from some convenient point on the guides or cylinder to some point horizontally in line on the cross-head or piston rod was measured. A similar measurement was then taken between the same two points with the locomotive on the other dead center. The difference between these two measurements in feet gave the stroke.

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40.	High	pressure,	right,	head	end	....
41.	"	"	"	crank	"	....
42.	"	"	left,	head	"	....
43.	"	"	"	crank	"	....
44.	Low	"	right,	head	"	....
45.	"	"	"	crank	"	....
46.	"	"	left,	head	"	....
47.	"	"	"	crank	"	....

The volume of clearance was obtained by placing the locomotive on the dead center and filling the clearance space with water from a vessel holding a known weight of water. The water remaining in the vessel was weighed and the rate of leakage from the clearance space observed. From these data the volume of the clearance space was readily calculated, and 100 times this volume, divided by the volume of piston displacement was the result desired. As a check, the clearances were calculated from measured dimensions and working drawings, but preference was given to the results obtained by the use of water.

With piston valve engines it was necessary to place the valve so that it blocked the steam port; a tell-tale hole was provided to allow the escape of air and to show the height of the water. By removing a cylinder cock, and using a hand pump, the water was forced in from below, and the amount ascertained. In only one case, that of the De Glehn locomotive, was it found impossible to obtain the volume of the clearance spaces by filling them with water; the figures shown for this locomotive were calculated from the drawings.

RECEIVER, CUBIC FEET.

48. Volume, right side ....
49. " left " ....

These items were ascertained in the same manner as the volume of clearances.

STEAM PORTS, INCHES.

(*For piston valves, the length equals the circumference of inside of bushing minus the sum of the widths of bridges.*)

50. High pressure admission, right, head end, length ......
51. " " " " " " width ....
52. " " " " crank " length ....
53. " " " " " " width ....
54. " " " left, head " length ......
55. " " " " " " width ....
56. " " " " crank " length ......
57. " " " " " " width ....
58. Low " " right, head " length ......
59. " " " " " " width ....
60. " " " " crank " length ......
61. " " " " " " width ....
62. " " " left, head " length ......
63. " " " " " " width ....
64. " " " " crank " length ......
65. " " " " " " width ....
66. High pressure exhaust, right, length ....
67. " " " " width ....
68. " " " left, length ....
69. " " " " width ....
70. Low " " right, length ....
71. " " " " width ....
72. " " " left, length ....
73. " " " " width ....

The length of the steam and exhaust ports given is not the actual length, but is that figure which, when multiplied by the actual width gives the actual area of the port. The measurements are given in this way to allow for the rounded corners usually found in cylinder ports.

PISTON RODS, DIAMETER, INCHES.

74. High pressure, right ....
75. " " left ....

76. Low pressure, right ....
77. " " left ....

TRAIL RODS, DIAMETER, INCHES.

78. High pressure, right ....
79. " " left ....
80. Low " right ....
81. " " left ....

The piston rods and tail rods were measured at several points by a micrometer caliper. The diameter given for each rod is the average of all measurements.

The Atchison, Topeka and Santa Fe locomotive No. 929, "Santa Fe" type, had tandem cylinders, so that it was impossible to obtain the diameter of the low pressure cylinders and of the piston rod between the high and low pressure cylinder heads, without removing the back head of the low pressure cylinder and the guides, or the high pressure cylinder. To save time, this measurement was not taken at St. Louis, but a member of the force was sent to Topeka, after the locomotive had been tested, and the measurements were then obtained.

VALVES.

82. Type ....
83. Design ....
84. Balanced area in per cent. of total..............................

The balanced area of the valve is the product of the dimensions to inside edges of balance strips or rings; the total area that of the entire face of valve.

85. Type of link motion..............................

GREATEST VALVE TRAVEL, INCHES.

86. High pressure, right ....
87. " " left ....
88. Low " right ....
89. " " left ....

Obtained with the reverse lever in full gear forward, by scribing the valve rod and measuring with a tram.

OUTSIDE LAP OF VALVE, INCHES.

90. High pressure, right, head end ....
91. " " " crank " ....
92. " " left, head " ....
93. " " " crank " ....
94. Low " right, head " ....

95. Low pressure, right, crank end......................
96. " " left, head " ....
97. " " " crank " ....

INSIDE LAP OF VALVE, INCHES.

98. High pressure, right, head end ....
99. " " " crank " ....
100. " " left, head " ....
101. " " " crank " ....
102. Low " right, head end ....
103. " " " crank " ....
104. " " left, head " ....
105. " " " crank " ....

The outside and inside laps were calculated from measurements of valve and valve seat and their relative positions at center of valve travel.

MISCELLANEOUS.

106. Cylinder lagging material ....
107. " jacket " ....
108. Lead, forward motion, head end, inches ....
109. " " " crank " " ....
110. " back " head " " ....
111. " " " crank " " ....
112. Leading crank ....

BOILER.

113. Type ....
114. Outside diameter, first ring, inches.....................

The outside diameter of the first or smallest ring of the boiler was calculated from the circumference as measured with a flexible steel tape.

TUBES.

115. Number ....
116. Outside diameter, inches............................
117. Thickness, inches.................................

As the thickness and outside diameter of tubes vary considerably after they have been in service, the nominal diameter and specified thickness were taken.

118. Length between tube sheets, inches...................

The length of tubes, between tube sheets, was obtained by measuring the length over beads of a number of tubes well distributed and deducting the thickness of tube sheet and beads.

119. Total fire area, square feet..............................

The total fire area of tubes was obtained by multiplying the area of cross section of inside of tube by the number of tubes.

120. Serve tubes, number of ribs..............................
121. " " square inches of inside surface in one inch of length ....

As a factor in obtaining the surface contour of the Serve tubes, a strip of adhesive tape was pressed into the form of the ribs of the tube. The length of this tape in inches equalled the square inches of surface in one inch of length.

122. ....
123. ....
124. Boiler pressure, pounds per square inch..............................

SUPERHEATER.

125. Number of tubes..............................
126. Outside diameter, inches..............................
127. Thickness, inches..............................
128. Length of tubes, inches..............................
129. ....
130. ....
131. ....

The dimensions of superheater tubes were found in the same way as already described for boiler tubes.

FIREBOX, INSIDE.

132. Length, inches..............................
133. Width, " ....

The length of the fire-box was measured at the level of the bottom of fire-door, and parallel to the line of rail, the width being the horizontal distance between side sheets at mid-length.

134. Depth, front end, inches ....
135. " back " " ....

The depth of fire-box was the measured distance (perpendicular to the rail), from grate surface to crown sheet at front and at back of fire-box.

136. Volume, cubic feet..............................

The volume of fire-box was calculated from dimensions of the fire-box above the surface of the grates, and checked from the drawings. In the case of locomotives equipped with brick arches in the fire-box, the volume of the arch pipes and bricks was subtracted from the volume of the fire-box as calculated from its dimensions.

137. Air inlets to ash pan (dampers closed) square feet........
138. " " " " " (" open) " " ....
139. ....
140. ....

FIRE DOORS.

141. Number ....
142. Area, square feet...................................
143. ....

GRATES.

144. Style ....
145. Total area, square feet.............................
146. " " dead grates, square feet....................
147. Width of air spaces, inches.........................

The width of the air spaces in grates was, with bar grates, the actual width of the openings; with finger grates, the maximum opening.

AIR INLETS.

148. Through firebox sides, square feet....................
149. " grates, " " ....

The area of the air inlets through the grates was calculated from drawings known to correctly show the grates.

150. Through fire doors, square feet.......................

The air inlet area through fire doors was the area of dampers or holes in fire door, when dampers were open as far as possible.

151. Total air inlets (No. 148), (No. 149) and (No. 150), square feet..
152. Ratio air inlets (No. 149) to grate area (No. 145)......
153. " " " (No. 151) " " " (No. 145)......

HEATING SURFACE, SQUARE FEET.

154. Of the tubes, water side..............................

The heating surface of the water side of the tubes was obtained by multiplying the circumference of the outside of tube, in feet, by the length between tube sheets, in feet, and by the number of tubes.

155. Of the tubes, fire side...............................

The heating surface of the fire side of the tube was obtained in a similar manner to Item No. 154, except that the internal diameter of the tube was used. In the case of Serve tubes the length over the ribs (No. 121) divided by twelve is the circumference in feet.

156. Of the firebox, fire side..............................

The heating surface of the fire-box was the area calculated from measurements of the fire-box sheets, above the level of the grates, less the total fire area of the tubes (No. 119), the area of fire doors (No. 142), and the area of air inlets through sides of fire-box (No. 148).

The surface of the fire side of the arch tubes, when present, was added to the heating surface of fire-box.

157. Of superheater, fire side..............................

In the heating surface of superheater was included any headers, etc., which formed part of the true superheating surface.

158. Total, based on inside of firebox and inside of tubes ..
159. " " " " " " " outside " " ...

The heating surface of the superheater, for a locomotive so equipped, was included in these items; using the fire sides of tubes and headers. The heating surface, based on the fire side, was used in all calculations in these tests.

BOILER VOLUMES.

(*With water surface at level of second guage cock.*)

160. Water space, cubic feet..............................
161. Steam " " " ....

To obtain the volume of the water and steam space in the boiler, the locomotive frame was leveled, and the boiler completely filled with water. The water was weighed out, down to level of second or middle gauge cock; from the weight of water corrected for temperature, the volume of steam space was calculated. By weighing out the remaining water in the same way the volume of water space was found.

The water contained in the boiler was also weighed out for each inch in height to obtain figures for correction, if differences of water level in the boiler existed between the beginning and the end of test.

EXHAUST NOZZLE.

162. Double or single..............................
163. Dimensions of right, inches ....
164. " " left, " ....
165. Area " right, square inches ....

166. Area of left, square inches..............................
167. Total area, square inches..............................

REVERSE LEVER.

168. High pressure cylinder, notches forward of center .....
169. Low " " " " " " .....
170. ....

RATIOS.

171. Heating surface (No. 158) to grate area (No. 145)......
172. Fire area through tubes (No. 119) to grate area (No. 145).
173. Firebox heating surface (No. 156) " " " (No. 145).
174. Tube surface (No. 155) to firebox heating surface (No. 156)..
175. Firebox volume (No. 136) to grate area (No. 145)......
176. ....
177. ....
178. ....

CONSTANT FOR DYNAMOMETER HORSE POWER.

(*power developed at one R. P. M. when pull is one pound.*)

179. ....

CONSTANTS FOR INDICATED HORSE POWER.

(*power developed at one R. P. M. and one pound M. E. P.*)

180. High pressure cylinder, right, head end ....
181. " " " " crank " ....
182. " " " left, head " ....
183. " " " " crank " ....
184. Low " " right, head " ....
185. " " " " crank " ....
186. " " " left, head " ....
187. " " " " crank " ....

PISTON DISPLACEMENT, CUBIC FEET.

188. High pressure cylinder, right, head end ....
189. " " " " crank " ....
190. " " " left, head " ....
191. " " " " crank " ....
192. Low " " right, head " ....
193. " " " " crank " ....
194. " " " left, head " ....
195. " " " " crank " ....

This was the length of stroke in feet multiplied by the difference between the area of cylinder and the area of piston rod or tail rod in square feet as was the case.

All instruments were read at intervals of ten minutes during the test. Observations of the more important facts were taken by two methods, and all calculations were carefully checked.

196. Duration of test, hours..............................

The duration of test, given in hours, and decimals of an hour, was the elapsed time from the start to the close of test.

SPEED.

197. Total revolutions....................................

A return crank, attached to one of the drivers, was connected to a rotating revolution counter, which was read at the beginning and end of test, and also at intervals of ten minutes. A reciprocating revolution counter was connected with the main supporting axle. From the diameters of the driving wheel and supporting wheel a factor was obtained by which the number of revolutions shown on supporting wheel counter were compared with the number shown by driving wheel counter in order to detect slipping of drivers should it occur.

A tachometer was also driven by the main supporting axle, and provided a check for the average revolutions.

198. Average revolutions per minute..........................

199. Equivalent speed in miles per hour.......................

200. " piston speed in feet per minute..............

POSITION OF LEVERS.

201. Reverse lever, notches from front end....................

202. ....

203. Throttle lever...

204. Coal corresponding to steam lost from boiler (lbs. per hour)

This coal lost was ascertained by dividing the steam wasted by calorimeters, etc. (Item No. 216) by the evaporation per pound of coal (Item No. 343).

205. ....

TEMPERATURE, DEGREES FAHRENHEIT.

206. Of smoke box, by thermometer...........................

For the smoke box temperature a thermometer, with carbon dioxide above the mercury, was used as a check on the indications of the pyrometer. It will be noted that the readings of these two instruments were usually very close together, so that the results given by a high reading mercurial thermometer may be used with confidence, when it is not considered desirable to install a thermo-electric pyrometer.

207. Of smoke box, by pyrometer..........................

Le Chatelier couples and a Millivoltmeter gave the smoke-box and fire-box temperatures.

The couple in the smoke-box remained in position; the couple in the fire-box was inserted through an opening in the side, about midway of its length, and at a height above the grate of about twelve inches. After it had been in position with the fire door closed a sufficient time to assume the temperature of the fire-box, readings were taken and the couple withdrawn from the fire-box.

208. Of laboratory, dry bulb..............................
209. " " wet " ....
210. " steam in branch pipe..........................

The temperature of the steam in branch pipe was calculated from the observed pressure of steam in the same and from the observed pressure and temperature of the steam in the calorimeter connected to the branch pipe.

211. Of feed water....................................

The feed water temperature was taken in the receiving tank.

212. Of firebox, by pyrometer..........................
213. ....
214. Horizontal vibration of pilot, inches..................
215. ....
216. Steam lost from boiler, etc. (lbs. per hour).............

The steam lost per hour was that used in the calorimeters and by leakage from the boiler through the safety valves, etc. As each calorimeter was adjusted to give a flow of about 200 pounds of steam per hour this item was considerable in some tests.

PRESSURE, POUNDS PER SQUARE INCH.

217. In boiler, average..................................
218. " " maximum ....
219. " " minimum ....
220. " branch pipe ....

Steam pressures were obtained by special test gauges; the gauge for indicating boiler pressure was located on the steam dome on the calorimeter pipe connection, and the gauge for branch pipe outside of smoke box.

221. In laboratory, barometric............................

The barometric pressure was measured by use of a mercurial barometer, readings being corrected for temperature, and converted into pounds per square inch.

DRAFT, INCHES OF WATER.

222. In smoke box, front of diaphragm......................
223. " " " back " " ....
224. " firebox ....
225. " ash pan ....

The draft was measured by "U" tube draft gauges, the readings of which were checked by recording draft gauges of an approved type.

INJECTORS.

HOURS IN ACTION.

226. Total, right ....
227. " left ....

QUALITY OF STEAM.

228. In dome ....
229. " branch pipe ....
230. Degrees of superheat in branch pipe....................
231. Factor of correction for quality of steam...............

The quality of steam in dome and branch pipe was obtained by Peabody throttling calorimeters, provided with mercurial gauges reading to tenths of a pound, and thermometers reading to half degrees.

The quality of steam, and degrees of superheat, for the throttling calorimeter, were calculated as follows:

Let x=the "quality of the steam" or the number of pounds of "dry" ("saturated") steam of the same boiler pressure per square inch and containing the same quantity of heat as one pound of steam under test. x therefore may be greater or less than unity according as the steam is superheated or moist and equal unity when that steam is dry or saturated.

λ=Total heat of dry steam due to the absolute boiler pressure.

r=Latent heat of dry steam due to the absolute boiler pressure.

q=Heat of the liquid due to the absolute boiler pressure.

$r+q=\lambda$

λ_1 =The "Total Heat" of dry steam due to the absolute pressure in the calorimeter.

t_1=The temperature due to saturated steam at calorimeter pressure.

t_s =The temperature of the steam in the calorimeter in any case.

t_{s_0}=The temperature of the steam in the calorimeter in case the steam in the boiler is dry.

k°=The number of degrees of superheat in case of superheated steam.

The following formula is then derived on the assumption that no heat is lost by the steam in its passage from the boiler to the calorimeter, and that 0.48 is the "Specific Heat" of steam.

$$xr+q=\lambda_1+.48\ (t_s-t_1)$$

consequently, the quality of steam, Items Nos. 228 and 229, is

$$x=\frac{\lambda_1+.48\ (t_s-t_1)-q}{r} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The steam under test is dry (saturated) when $x=1$ and in that case, t_s becoming t_{s_0} as defined above.

$$t_{s_0}=\frac{(r+q)-\lambda_1+.48\ t_1}{.48}=\frac{\lambda-\lambda_1+.48\ t_1}{.48};$$

so that when the temperature t_s in the calorimeter is higher than t_{s_0} or that due to dry steam, the steam is superheated and the number of degrees of superheat, Item No. 230, will be $t_s - t_{s_0} = k^\circ$

$$k^\circ=t_s-\frac{\lambda-\lambda_1+.48\ t_1}{.48}=\frac{\lambda_1+.48\ (t_s-t_1)-\lambda}{.48}=\frac{(x-1)\ r}{.48} \ldots\ldots (2)$$

When the temperature in the calorimeter is less than t_{s_0} the priming is $(1-x)$, x being found as per formula above given. If, however, t_s drops to t_1 the limit of the calorimeter is reached and $x=x_0=\frac{\lambda_1-q}{r}$ at most, and the priming $(1-x_0)=1-\frac{\lambda_1-q}{r}=\frac{\lambda-\lambda_1}{r}$ at least.

Therefore, for any case where t_1 is equal to t_s, the priming is equal to or greater than the capacity of the calorimeter, and to determine such greater amount of priming, Carpenter's separating calorimeter, also attached to the dome on the same connection, was used whenever the temperature in the calorimeter fell close to, or to within, say, 5° of the limit referred to.

In this case, the Quality x was determined as described by Carpenter in his "Text Book of Experimental Engineering," or as follows:

Let w=Weight of dry steam discharged at the exhaust orifice of the calorimeter, the amount being known from calibration to agree very approximately with Napier's Rule, namely, "The flow in pounds per second"=1-70th part of the product obtained by multiplying the pounds per square inch absolute pressure in calorimeter by the area of the orifice in square inches.

W=Weight of the water drawn from the separator of the calorimeter.

R=Weight of the water of condensation in the calorimeter, due to radiation from the same.

And if we now call W_1, the portion left of W after deducting the radiation, the weight of dry steam that would have been discharged had there been no radiation, is w+R and the total steam and water delivered to the calorimeter is

$$(W_1 + R) + w = W + w, \qquad \text{so that}$$

$$x = \frac{w + R}{W_1 + R + w} = \frac{w + R}{W + w}$$

If the radiation is neglected, $x = \frac{w}{w + W}$ ....(3)

which with the instrument provided will be considered correct, as the radiation loss is very small.

The "quality of steam" being thus determined, the "correction for quality of steam" is found as follows:

Let F="The factor of correction for quality of steam" desired.

Let x, λ, r and q stand for the same quantities as in the above formula for the quality of the steam.

q_1="Heat of the Liquid" due to the feed water, the temperature of which was observed.

Then the amount of heat actually added to each pound of feed water, making steam of quality x, was

$$x\lambda+(1-x)\,q-q_1 \text{ or } x\,(\lambda-q_1)+(1-x)\,(q-q_1) \text{ and } (\lambda-q_1)$$

is the amount of heat that would have been required by each pound of the same feed water to make dry steam at the same pressure.

Consequently, the amount of dry steam equivalent to one pound of the actual mixture (i. e., the amount of dry steam requiring for its generation the same supply of heat as that actually supplied to each pound of feed water) was

$$F=\frac{x\lambda+(1-x)\,q-q_1}{\lambda-q_1}=\frac{x\,(\lambda-q_1)+(1-x)\,(q-q_1)}{\lambda-q_1}=$$

$$x+(1-x)\frac{q-q_1}{\lambda-q_1} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

Formula (4) is the general one for F and may be used in any case; but when the steam is superheated, x is greater than unity, consequently more convenient will be

$$F=x-(x-1)\frac{q-q_1}{\lambda-q_1} \quad \ldots\ldots\ldots\ldots\ldots \quad (4a)$$

and as the degrees of superheat are known from the formula (2) for degrees of superheat, the simpler formula

$$F=1+\frac{.48\,k^{\circ}}{\lambda-q_1} \quad \ldots\ldots\ldots\ldots\ldots \quad (4b)$$

may be used, that is, of the formulæ, (4), (4a) and (4b) each one gives the same value for "the factor F of correction for quality of steam."

In case observations are made of the actual temperature T and of the pressure (p) of the superheated steam itself, the degrees of superheat will be more directly obtained by subtracting from this T the (t) given in Peabody's steam tables corresponding to the pressure (p). The value of F in that case is also more directly obtained from

$$F=\frac{(\lambda-q_1)+.48k^{\circ}}{\lambda-q_1}=1+\frac{.48\,k^{\circ}}{\lambda-q_1} \quad \ldots\ldots\ldots \quad (5)$$

as already given.

COAL, SPARKS AND ASH.

232. Coal fired, kind ....
233. " " total, pounds...............................
234. " as fired, per cent. of moisture...................

All coal was brought to the plant in low side gondola cars, and was shoveled over the sides of the car into boxes of a capacity of about 1,000 pounds each; these boxes were stored near the back end of the locomotive and were moved by the traveling crane, as needed, to a calibrated platform scale, weighed, and the coal box moved to the firing platform and the coal dumped. After dumping and before sprinkling, a small sample was taken and placed in a covered box, so located that the coal contained was not exposed to heat. The empty box was weighed on the platform scale, and the difference of the gross and tare weights so obtained gave the coal used; the amount set aside as sample being subtracted from the total coal charged to the boiler.

About 60 pounds of coal were taken as a sample; this was crushed to the size of an almond and reduced by quartering to about five pounds. It was then ground fine and reduced to half a pound by further quartering, after which it was pulverized and a regular chemist's sample taken. It had been intended to dry about 15 pounds to determine the moisture, and an electric heater was provided for that purpose, but the temperature in the drying pan varied greatly between different parts of the pan, beside which difficulties arose in securing the weights accurately; again, as the ash combustible and moisture were found by chemical analysis, it was finally decided to take the moisture obtained from the chemist's analysis, and abandon the use of the electric dryer. The analysis was made as soon as possible after the test closed, but the moisture was obtained on the day of the test.

235. Dry coal, fired, total, pounds..........................

The total dry coal fired was obtained by deducting from the total coal fired the weight of moisture.

236. Combustible, by analysis, total, pounds..................
237. Ash, by analysis, total, pounds.........................

No attention was paid to the ashes in the ash-pan, as it was felt that the analysis of the coal gave a more reliable figure for the ash than weighing the actual ash, because the draft in a locomotive fire-box is so great as to draw a part of the ashes through the flues and give incorrect data if actual weights were taken. If the ash was found by analysis, the combustible had necessarily to be obtained in the same manner.

238. Cinders collected in smoke box, total, pounds............

The smoke box was cleaned at the beginning of test and at the close, and the quantity of cinders which had collected during the test was weighed by an accurate scale.

239. Sparks discharged from stack, total, pounds..............

The stack, by which the smoke was removed from the building, was provided with a deflector and a receptacle into which the sparks which struck the deflector fell. This receptacle was cleaned at commencement of test and at close, the sparks which collected during the test being carefully weighed.

It was not found possible to catch all the sparks passing up the stack, as the force of the draft on the heavier tests carried some of them out at the top of the smoke stack of the plant. These sparks fell on the roof of the building, and for the total period of the tests were estimated to weigh about 97,000 pounds. The cinders caught in the front end and the sparks caught in the stack amounted to 53,500 pounds for the same period. As about 750 tons of coal were burned the cinders and sparks were about ten per cent. of the total weight of fuel.

240. Cinders and sparks, total, pounds......................

ANALYSIS OF COAL.

241. Fixed carbon, per cent............................
242. Volatile matter, per cent..........................
243. Moisture, per cent...............................
244. Ash, per cent..................................
245. Sulphur, determined separately, per cent................
246. ....
247. ....

The analysis of the coal was made in accordance with the method decided on by the Committee of the American Chemical Society, and given in Volume 21, No. 12, of their Journal. One aproximate analysis of coal was made for each test.

CALORIFIC VALUE IN B. T. U. PER LB. OF FUEL.

248. Of dry coal ....
249. " combustible ....
250. " cinders ....
251. " sparks ....
252. ....

The calorific value of the coal, cinders and sparks was determined in the Thompson calorimeter for each test.

ANALYSIS OF SMOKE BOX GASES.

253. Oxygen, O, per cent...............................
254. Carbon monoxide, CO, per cent.......................
255. Carbon dioxide, CO_2, per cent.........................
256. Nitrogen, N, per cent...............................
257. ....
258. ....

The analysis of smoke box gases was conducted by the use of the Orsat apparatus, three analyses being made for each test.

WATER, IN POUNDS.

259. Delivered to injectors...............................

The water used by the boiler passed through two calibrated water meters to two steel measuring tanks holding about 1,500 pounds of water each; and from thence to a receiving tank holding about 17,000 pounds of water.

The measuring tanks rested on calibrated platform scales, so that their capacities could be calibrated at frequent intervals, correction being made for temperature.

The total water delivered to injectors was obtained by actually weighing the water in the tanks; in no case was it necessary to rely on their calibrated capacity.

At the beginning of test the levels of water in the boiler and receiving tank were noted; the levels of water in both were allowed to fall slightly during the test. At the close of the test sufficient water was fed into the receiving tank to restore the initial level. The level in the boiler was noted, and when not the same as at the start, a correction was made.

The quantities found by the measuring tanks were checked by two meters. Provision was made to catch and measure the small amount of water wasted in filling the tanks, the meter readings less this waste were a check on the quantity delivered by the measuring tanks.

260. Lost, from boiler................................
261. " from ....
262. " " ....
263. " total ....

The water which escaped from the injector overflow pipes was caught and returned to the receiving tank; and no credit was given the boiler for the rise in temperature, if any, of this water.

In some of the light tests, the injectors were started so often that the quantity of water wasted was large; in these tests the water in the overflow tanks was measured by calibrating the tanks and noting the number of times they were emptied.

Care was taken to prevent leakage from the boiler; the air pump and steam heat throttles were disconnected so that leakage would be detected and the throttles made tight, but when necessary, leakage tests were made on boiler after close of the test.

264. Delivered to boiler and presumably evaporated.

DYNAMOMETER.

DRAWBAR PULL IN POUNDS.

265. Average ....
266. Maximum ....
267. Minimum ....

The pull exerted by the locomotive was measured by a traction dynamometer, already described on pages 42 to 47.

The maximum and minimum draw-bar pulls were found by measuring the diagram after the test.

The drawbar pull as recorded in these tests necessarily does not take into account the wind resistance nor the resistance due to the friction of the engine truck and trailing wheels and tender.

CUT-OFF, PER CENT. OF STROKE.

268. High pressure cylinder, right, head end................
269. " " " " crank " ....
270. " " " left, head " ....
271. " " " " crank " ....
272. Low " " right, head " ....
273. " " " " crank " ....
274. " " " left, head " ....
275. " " " " crank " ....

RELEASE, PER CENT. OF STROKE.

276. High pressure cylinder, right, head end................
277. " " " " crank " ....
278. " " " left, head " ....
279. " " " " crank " ....
280. Low " " right, head " ....
281. " " " " crank " ....
282. " " " left, head " ....
283. " " " " crank " ....

BEGINNING OF COMPRESSION, PER CENT. OF STROKE.

284. High pressure cylinder, right, head end................
285. " " " " crank " ....
286. " " " left, head " ....
287. " " " " crank " ....
288. Low " " right, head " ....
289. " " " " crank " ....
290. " " " left, head " ....
291. " " " " crank " ....

The points at which cut-off, release and beginning of compression took place, were determined by inspection of the card. This was done by the same method and same individual throughout the entire series of tests.

The length of each indicator card was measured and an average obtained for cards from each end of each cylinder; the length of stroke up to the time of cut-off was measured and averaged in a similar manner. The percentage that this average length of cut-off formed of the average length of card, is the result on the data sheet. The per cents. of stroke at which the other events mentioned, took place, were calculated in a similar manner.

PRESSURES FROM INDICATOR CARDS.

INITIAL PRESSURES, POUNDS PER SQUARE INCH.

292. High pressure cylinder, right, head end................
293. " " " " crank " ....
294. " " " left, head " ....
295. " " " " crank " ....
296. Low " " right, head " ....
297. " " " " crank " ....
298. " " " left, head " ....
299. " " " " crank " ....

The pressures of steam corresponding with the several events of stroke in cylinder, as shown by the indicator card, were measured by appropriate scale, and the results for each end of each cylinder averaged for each event. The average thus obtained was corrected for the error of the spring under the conditions and pressure, i. e., whether under increasing or decreasing pressure.

300. Factor of evaporation..............................

The factor of evaporation $= \frac{\lambda - q_1}{965.8}$ when

λ=total heat of steam at observed pressure.

q_1=heat of feed water at observed temperature.

STEAM CHEST PRESSURES, POUNDS PER SQUARE INCH.

301. High pressure, right side ....
302. " " left " ....
303. Low " right " ....
304. " " left " ....
305. ....

Indicator cards were taken from steam chest. The pressure given was the average pressure of these cards.

PRESSURES AT CUT-OFF, POUNDS PER SQUARE INCH.

306. High pressure cylinder, right, head end................
307. " " " " crank " ....
308. " " " left, head " ....
309. " " " " crank " ....
310. Low " " right, head " ....
311. " " " " crank " ....
312. " " " left, head " ....
313. " " " " crank " ....

PRESSURES AT RELEASE, POUNDS PER SQUARE INCH.

314. High pressure cylinder, right, head end................
315. " " " " crank " ....
316. " " " left, head " ....
317. " " " " crank " ....
318. Low " " right, head " ....
319. " " " " crank " ....
320. " " " left, head " ....
321. " " " " crank " ....

PRESSURES AT BEGINNING OF COMPRESSION, POUNDS PER SQ. INCH.

322. High pressure cylinder, right, head end................
323. " " " " crank " ....
324. " " " left, head " ....
325. " " " " crank " ....
326. Low " " right, head " ....
327. " " " " crank " ....
328. " " " left, head " ....
329. " " " " crank " ....

See note after No. 299.

LEAST BACK PRESSURE, POUNDS PER SQUARE INCH.

330. High pressure cylinder, right, head end................
331. " " " " crank " ....
332. " " " left, head " ....
333. " " " " crank " ....
334. Low " " right, head " ....
335. " " " " crank " ....
336. " " " left, head " ....
337. " " " " crank " ....

The least back pressure was measured in the same way as the pressures under Items Nos. 292 to 299, and the results averaged.

The exact location on the card of the point of least back pressure varies somewhat on different cards of the same test.

SUMMARY OF AVERAGE RESULTS.

BOILER.

338. Dry coal fired, per hour, pounds......................
339. " " " " " per sq. ft. of grate surface, lbs...

EVAPORATION, POUNDS.

340. Moist steam per hour................................
341. Dry " " " ....

The "moist steam per hour," Item No. 340, was the average water evaporated by boiler per hour uncorrected for moisture in steam, while "dry steam per hour," Item No. 341, was corrected for moisture, or superheat, by multiplying No. 340 by the "factor (F) of correction for quality of steam," Item No. 231.

342. Dry steam per hour per sq. ft. of heating surface.........
343. " " " pound of dry coal......................

EQUIVALENT EVAPORATION FROM AND AT 212 DEGREES F.

344. Per hour, pounds..................................

Found by multiplying the dry steam per hour, Item No. 341, by the factor of evaporation, Item No. 300.

345. Per hour per sq. ft. of heating surface, pounds..........

346. " pound of coal as fired, pounds...................

Found by dividing the equivalent evaporation per hour, Item No. 344, by the weight of coal per hour as fired, Item No. 233÷ Item No. 196.

347. Per pound of dry coal, pounds........................

Found by dividing the equivalent evaporation per hour, Item No. 344, by the weight of dry coal per hour, Item No. 338.

348. Per pound of combustible, pounds.....................

Found by dividing the equivalent evaporation per hour, Item No. 344, by the weight per hour of combustible, Item No. 236÷ Item No. 196.

349. Boiler horse power ....

Obtained by dividing the equivalent evaporation per hour, Item No. 344, by 34.5.

350. Efficiency of boiler...................................

Found by multiplying the equivalent evaporation per pound of dry coal, Item No. 347, by 965.8, and dividing the product by Item No. 248, the number of thermal units in one pound of dry coal.

No credit was given the boiler for heat units used in evaporating moisture contained in fuel as fired.

SUMMARY OF AVERAGE RESULTS.

ENGINE.

Mean Effective Pressure, Pounds Per Square Inch.

351.	High	pressure	cylinder,	right,	head	end	....
352.	"	"	"	"	crank	"	....
353.	"	"	"	left,	head	"	....
354.	"	"	"	"	crank	"	....
355.	Low	"	"	right,	head	"	....
356.	"	"	"	"	crank	"	....
357.	"	"	"	left,	head	"	....
358.	"	"	"	"	crank	"	....

All indicator cards were integrated twice by different computers.

After the average mean effective pressure of the indicator cards for each end of each cylinder had been ascertained, the card most nearly approximating the average was selected to represent the test. When these cards were subject to correction, resulting from a calibration of the indicator spring, the following method was used:

Vertical lines dividing the length of card into ten or twelve equal parts were drawn. At the points where these lines intersected the lines of the card, the card was corrected (correction curves having been made for each spring); if an increasing pressure, for the error of the spring under similar conditions; if descending, in like manner. A new card was drawn through the points thus located and the relation of the area of the rectified to the actual card gave a factor which was used in finding the corrected M. E. P.

The corrected average area of card, divided by the average length of card, and multiplied by the scale of spring used, gave the mean effective pressure.

RECEIVER.

359. Pressure, right side ....
360. " left " ....

This was observed by gauges attached as closely as possible to the receivers.

NUMBER OF EXPANSIONS.

361. Right side, head end ....
362. " " crank " ....
363. Left " head " ....
364. " " crank " ....

Found by dividing the volume at release plus the volume of clearance, by the volume at cut-off plus the volume of clearance. For head end of right cylinder, on simple locomotives,

Number of expansions =

$$= \frac{\text{No. } 276 \times \text{No. } 188 + \text{No. } 40 \times \text{No. } 188}{\text{No. } 268 \times \text{No. } 188 + \text{No. } 40 \times \text{No. } 188} = \frac{\text{No. } 276 + \text{No. } 40}{\text{No. } 268 + \text{No. } 40}$$

The formula for the other items are similar in form, with the corresponding per cents. of stroke substituted.

For compound locomotives, the form of the expression used is as follows:

$$\frac{\text{Volume at Release, L. P. Cylinder} + \text{Volume of Clearance, L. P. Cylinder}}{\text{Volume at Cut-Off, H. P. Cylinder} + \text{Volume of Clearance, H. P. Cylinder}}$$

INDICATED HORSE POWER.

365. High pressure cylinder, right, head end.................
366. " " " " crank " ....
367. " " " left, head " ....
368. " " " " crank " ....
369. Low " " right, head " ....
370. " " " " crank " ....
371. " " " left, head " ....
372. " " " " crank " ....

DIVISION OF POWER.

373. High pressure cylinder, right side......................
374. " " " left " ....
375. Low " " right " ....
376. " " " left " ....
377. Right side, total......................................
378. Left side, " ....
379. Total Indicated Horse Power.........................

The Indicated Horse Power was found by multiplying together the I. H. P. constant, the average revolutions per minute and the mean effective pressure.

For the head end of right high pressure cylinder, the Indicated Horse Power = No. 180 × No. 198 × No. 351.

The formula for the other items is similar in form, with the corresponding quantities substituted.

PER INDICATED HORSE POWER HOUR.

380. Dry coal, pounds......................................
The dry coal per indicated horse power hour was found by dividing the dry coal per hour (Item No. 338), less the coal corresponding to steam lost by calorimeter, etc. (Item No. 213), by the indicated horse power (Item No. 379), or

$$\text{Dry coal per I. H. P. Hour} = \frac{\text{No. } 338 - \text{No. } 204}{\text{No. } 379}$$

381. Dry steam, pounds......................................

Found by dividing the dry steam per hour (Item No. 341), less the steam used by calorimeters or other instruments (Item No. 216), by the total Indicated Horse Power (Item No. 379).

$$\text{Dry steam per I. H. P. H.} = \frac{\text{No. 341} - \text{No. 216}}{\text{No. 379}}$$

382. B. T. U. ....

Obtained by multiplying the dry coal per I. H. P. hour (Item No. 380), by the calorific value of one pound of dry coal (Item No. 248).

SUMMARY OF AVERAGE RESULTS.

LOCOMOTIVE.

383. Dynamometer horse power.............................

Found by multiplying together the D. H. P. constant (Item No. 179), the average revolutions per minute (Item No. 198), and the average draw-bar pull (Item No. 265, or D. H. P. = No. 179 × No. 198 × No. 265).

384. Dry coal per D. H. P. hour, pounds.....................
385. " steam " " " " ....
386. B. T. U. " " " ....

The pounds of coal and steam and the B. T. U. per D. H. P. hour were found in the same manner as the corresponding items for indicated horse power hour.

PER ONE MILLION FOOT POUNDS AT DRAW-BAR.

387. Dry coal, pounds....................................
388. " steam, " ....
389. B. T. U. ....

The coal, steam and B. T. U. per one million foot-pounds at draw-bar were found in a similar manner to Items Nos. 380 to 382.

390. I. H. P. per square foot of heating surface..............
391. " " " " " grate " ....
392. D. H. P. " " " " heating " ....
393. " " " " " grate " ....
394. Tractive power based on M. E. P., pounds..............

Since the I. H. P. (Item No. 379) has already been determined from the mean effective pressure as a basis, the tractive force T can most conveniently be obtained as the product of the constant ratio (33000 to No. 13) by the variable ratio No. 379 to No. 198 or by formula as follows:

$$T = \frac{33000}{\text{No. } 13} \times \frac{\text{No. } 379}{\text{No. } 198}$$

This was checked by obtaining the tractive power of each cylinder separately directly from the mean effective pressure, Nos. 351 to 358, and taking their sum; for the high pressure cylinder, right side, head end, the formula would then be as follows:

$$T_h = 0.7854 \times \frac{\text{No. } 351\ (\text{No. } 32^2 - \text{No. } 78^2)\ \text{No. } 36}{\text{No. } 13}$$

and correspondingly for each of the other cylinders, treating the head and crank ends separately.

MACHINE FRICTION OF LOCOMOTIVE IN TERMS OF.

395. Horse power ....

This is the difference between the average indicated horse power and the average dynamometer horse power. This does not take into account the friction due to engine truck and trailing wheels and axles.

396. M. E. P., pounds.......................................

For simple engines this is the machine friction in horse power (No. 395) divided by the average horse power constant and the average revolutions per minute. This quantity was not calculated for compound locomotives, as it must be referred either to the high or to the low pressure cylinder, or to a simple cylinder equivalent to both. In either case the results are not valuable.

397. Draw-bar pull, pounds ....

This is the frictional horse power, No. 395, multiplied by 33000 to convert it into foot-pounds, divided by the distance in feet per minute. Or maehine friction in terms of pounds draw-bar pull

$$= \frac{\text{No. } 395 \times 33000}{\text{No. } 198 \times \text{No. } 13}$$

EFFICIENCY.

398. Machine efficiency of locomotive, per cent..............

This is 100 times the ratio of the D. H. P., No. 383, to the I. H. P., No. 379.

399. Efficiency of locomotive, per cent......................

Found by dividing the heat equivalent of one horse power for one hour, by the B. T. U. per dynamometer horse power hour No. 386, shown by test. This quantity multiplied by 100 gave the efficiency in per cent.

$$\text{Efficiency of locomotive per cent} = \frac{254498.7}{\text{No. 386}}$$

RATIOS.

400. Total weight of locomotive to maximum I. H. P..........
401. " heating surface to maximum I. H. P...............

402. Millions of foot-pounds at draw-bar per hour............

The number of foot-pounds at draw-bar was found by multiplying the average draw-bar pull (item No. 265), by the average circumference of the driving-wheels in feet (item No. 13), and by the total revolutions (item No. 197).

As the coal, steam, etc., were reduced to hourly quantities, for convenience, the product obtained by the multiplication in the preceding paragraph was divided by the duration of the test in hours (item No. 196), and by one million.

Millions of foot-pounds at draw-bar per hour (item No. 402)

$$= \frac{\text{No. } 265 \times \text{No. } 13 \times \text{No. } 197}{\text{No. } 196 \times 1{,}000{,}000}$$

403. Maximum indicated horse power.....................

This quantity was selected by examining the indicator cards and calculating the horse power on those sets which appeared to show the largest horse power. As the speed was unusually constant, it was almost always the set of cards showing the highest mean effective pressure.

404. ....
405. ....
406. ....
407. Date of test ....

GENERAL SUMMARY OF AVERAGE RESULTS.

All of the items given under this heading are contained in earlier statements, but are here grouped together, thus giving in a condensed form the most important facts.

196. Duration of test, hours ...
198. Number of revolutions per minute ...
199. Speed in miles per hour ...
268 to 271. Approximate cut-off in high pressure cylinder, in per cent. of stroke ...
203. Position of throttle ...
217. Boiler pressure in pounds per square inch ...
220. Branch pipe " " " " " " ...
222. Draft in front of diaphragm, inches of water ...
338. Dry coal fired per hour, pounds ...
341. " steam used " " " ...
347. Equivalent number of pounds of water from and at 212° Fahr., per pound of dry coal ...
379. Indicated horse power ...
383. Dynamometer " " ...
395. Frictional " " ...
265. Draw-bar pull, pounds ...
380. Dry coal per I. H. P. hour, pounds ...
384. " " " D. H. P. " " ...
381. " steam " I. H. P. " " ...
385. " " " D. H. P. " " ...
350. Efficiency of boiler ...
399. " " locomotive ...

The observations made, covered all data usually observed in boiler and engine tests, but only the principal conclusions are presented in this volume. All the essential facts are given so that further analysis may be made.

MAXIMUM TRACTIVE EFFORT.

The formulæ used to obtain the tractive effort for the different locomotives were as follows:

T. F. = Maximum tractive force at circumference of drivers.

P = Rated boiler pressure in pounds per square inch above atmosphere.

d_H = Diameter of high pressure cylinder, inches (or diameter of cylinders of simple locomotives).

d_L = Diameter of low pressure cylinder, inches.

S = Stroke of piston, inches.

R = Ratio of low pressure cylinder to high pressure cylinder or $\frac{d_L^2}{d_H^2}$

D = Diameter of driving wheels, inches.

FORMULAE FOR MAXIMUM TRACTIVE FORCE, T. F.

Type of Locomotive	Working Simple	Working Compound
Simple, two cylinder.	$\frac{.8\,P\,d_H^2\,S}{D}$	———
Cross Compound, two cylinder.	$\frac{.8\,P\,d_H^2\,S}{D}$	$\frac{.8\,P\,d_L^2\,S}{[R+1]\,D}$
Tandem Compound, four cylinder.	$\frac{1.15\,PS}{D}[.66\,d_H^2+.25\,d_L^2]$	$\frac{PS}{D}[.66\,d_H^2+.25\,d_L^2]$
Balanced Comp'd. four cylinder.	$\frac{1.6\,P\,d_H^2\,S}{D}$	$\frac{1.6\,P\,d_L^2\,S}{[R+1]\,D}$

CHAPTER IX.

METHODS OF CONDUCTING TESTS.

In preparing for a test, the locomotive was started and gradually brought to the required conditions of speed and cut-off, and after ten or fifteen minutes running under these conditions the test was begun. A warning signal of four bells was given five minutes before the test began, and fifteen seconds before each reading a signal of two bells was sounded; one bell being given to mark the exact time of the observation.

At the start, all water levels were noted, and all observations taken; thereafter all coal and water used was taken from a weighed supply.

Throughout the test, conditions were kept as uniform as possible, observations being taken at ten minute intervals.

During the test a graphical log was kept, quantities being plotted on it every ten minutes. This log gave a ready means of detecting errors in observations, or inequalities, almost as soon as they occurred, so that the observations could be checked and the error detected and corrected at once.

To minimize the chances for error the following observations were taken in duplicate: Feed water, coal, boiler pressure, draft, revolutions, and temperature of smoke-box.

The feed water was weighed and checked by meter readings.

The coal was weighed on a platform scale and also by a suspended scale. It was found that the weights given by the suspended scale were not accurate, so that its use was given up, and the readings of the platform scale taken by two observers.

The boiler pressure was read from a gauge on the dome, and checked by a gauge in the cab. The draft pressures were taken by "U" tubes and checked by recording gauges.

The revolutions were read every ten minutes from a counter attached to a return crank on the driving wheel, and checked by a revolution counter connected by gearing to the supporting wheels. There was also a tachometer and an Auto Meter.

The temperature of the smoke-box was obtained with a Le Chatelier pyrometer and also with a mercurial thermometer, with carbon dioxide above the mercury.

A separate indicator was used at each end of each cylinder, the pipes being as short as the design of the locomotive would permit.

It was not found advisable to run tests longer than three hours, for with longer tests it was impossible to get two in one day, which was made necessary by the delays experienced. Tests at 240 revolutions were run for two hours; at 280, for an hour and a half; and at 320 revolutions, for one hour.

In the tests at 240 and 280 revolutions this length of time gave a run of approximately 100 miles, and such a run would nearly exhaust the rod oil cups.

The only test at 320 revolutions was stopped at the end of one hour, because it was not known how well the oil in the eccentric strap and rod cups was holding out, and it was felt that this very high speed involved risks that it was not wise to incur longer than the minimum time necessary to get reliable data.

In comparing these tests with road tests lasting for longer periods, the constancy of the conditions should not be forgotten, so that the length of run under the chosen conditions on the plant was much longer than the portion of a road test under any similar conditions.

It was usually desirable to vary the retarding force of the brakes in proportion to the weight on the drivers, except in the case of the front pair, which being more likely to get particles of steam or oil on the tread, had a greater tendency to slip. For this reason, a lower pressure was always carried on this pair of brakes.

The tests were ended as they began, the fire being brought to as nearly as possible the condition at the beginning, and the water level in the boiler was brought to the same level as at starting. This was not done by feeding in any quantity of water at one time, but by keeping the level slightly below the starting level during the test until about twenty minutes before the end, when the injectors were adjusted to gradually increase the water level until it was at the mark set at the beginning. Owing to the very uniform conditions it was possible to do this in all but five or six tests, when there was a slight difference in level, which was calculated from the calibration of the boiler per inch difference of level on the glass. When used, these calibrations were corrected for temperature.

After the last observation, the log sheets were worked up by those who had taken the observations, checked by others, and then handed to the computers who calculated and tabulated the results of the tests.

COUNTERBALANCE TESTS.

The balancing of the locomotive was measured in three ways; the critical speed, the horizontal vibrations at pilot, and the varying pressures of the driving wheels on the supporting wheels.

The critical speed was obtained by running the locomotive without dash-pots in the safety-bars, and observing the lowest speed at which the pull of the locomotive changed to a push and back again. This action was due to the horizontal component of the unbalanced reciprocating parts reversing the pull of the locomotive. Under road conditions the momentum of the mass of the locomotive overcomes these momentary variations, but on the plant they were at once apparent, as the locomotive had no momentum as a whole. Of course, at very high speeds on the road these movements become apparent.

To obtain the varying wheel pressures, wires were run under the driving wheels, and measured with a micrometer caliper at intervals of five inches, the method followed being that originated by Prof. W. F. M. Goss. Diagrams of these wires are shown in the appendix for each passenger locomotive, an explanation of the notation being given on page 451. They were seldom rolled from the original thickness of .06 inch to less than .02 inch and did not give a quantitative record of the intensity of the pressure of the wheel on the rail, but indicated the points at which this pressure decreased to a marked degree and whether the driving wheel left the supporting wheel.

The tires of the driving wheels were nicked with a chisel to locate the points on the wires in relation to the balance weights.

FUEL.

It was originally intended to test locomotives constructed for burning bituminous and others for burning anthracite coal, but the time was so short, and the total number of locomotives which could be tested so small, that it was thought best to reduce the variables as much as possible. It was, therefore, decided not to test any locomotives constructed for burning anthracite coal.

Before the tests were begun considerable time was spent in making analyses of coals in order to get a bituminous fuel having high fixed carbon, little ash, producing little smoke, and with as little tendency to clinker as possible. The coal finally selected came from the Scalp Level mines (near Johnstown, Pa.) owned by the Berwind-White Coal Mining Company. The coal was of good quality but friable, and when the draft was strong, some of the finer particles were drawn through the tubes into the smoke-box.

The heating value per pound of dry coal averaged more than 14,000 B. T. U.

The approximate analyses of the coal was:

Fixed carbon	75.85%
Volatile combustible	16.25
Ash	7.00
Moisture	.90
	100.00%
Sulphur determined separately	.90%

The ultimate analysis was

Carbon	84.20%
Hydrogen	4.28
Nitrogen	1.44
Oxygen	2.94
Sulphur	.80
Ash	6.34
	100.00%

Calorimeter test .... 15,025 B. T. U.

The Berwind-White Coal Mining Company presented to the testing plant, all the coal used, making this contribution in the interests of science.

WATER.

The water used was taken from the mains of the city of St. Louis, and was supplied free by the Exposition Company. Water was used both for the locomotive boilers and for operating the brakes, the total quantity being very large. The water used in the boilers was purified by the apparatus of the Kennicott Water Softener Company, which was installed by the latter company near the testing plant, and no charge was made for treating the water.

CHAPTER X.

SELECTION OF LOCOMOTIVES.

To broaden the field of investigation, it was decided to select locomotives differing as widely as possible in type in order to secure results affording the greatest range of comparisons; for clearly the real value of the work lay in that direction. For this reason the tests were not to be confined solely to locomotives owned by the Pennsylvania Railroad, but other American railroads and locomotive builders, as well as representatives of foreign governments to the Exposition, were asked to furnish locomotives for test. Favorable answers were received stating that such locomotives as might be designated would be promptly provided.

The following preliminary program was prepared:

ATCHISON, TOPEKA & SANTA FE.

1 Atlantic type, 4 cylinder balanced compound, Baldwin Locomotive Works' design.

1 Santa Fe type (Decapod with trailer), 4 cylinder tandem compound, Baldwin Locomotive Works' design.

NEW YORK CENTRAL & HUDSON RIVER.

1 Atlantic type, 4 cylinder balanced compound, American Locomotive Company's design.

1 Atlantic type, piston valves.

PENNSYLVANIA RAILROAD COMPANY.

1 Atlantic type, 4 cylinder balanced compound, De Glehn design.

1 Atlantic type, "D" valves.

1 Consolidation type, wide fire-box.

MICHIGAN CENTRAL.

1 Pacific type, simple, wheels 75 inches diameter.
1 Consolidation type, cross-compound, wide fire-box.

LAKE SHORE & MICHIGAN SOUTHERN:

1 Consolidation type, simple, narrow fire-box.

The Imperial German Commissioner General advised also that two firms, Henschel & Sohn, of Cassel, Germany, and the Hannoversche Machinenbau Actien Gesellschaft of Linden, Germany, would each send one locomotive to St. Louis. The Commissioners from France and England did not secure locomotives for test from any firms or railroads in their respective countries.

In selecting locomotives the endeavor was to secure variety in the essential principles of design. As the time was limited little attention could be given to the influence of minor details; the main object being to establish the economic performance of a number of typical locomotives when operating under a wide range of conditions. No type of locomotive was tested which had not been in successful road service.

The final selection of locomotives to be tested and the order in which the tests were to be made was decided upon by the Committee and was as follows:

No. 1, Pennsylvania Railroad, Consolidation type, simple, wide fire-box.
No. 2, Lake Shore & Michigan Southern, Consolidation type, simple, narrow fire-box.
No. 3, Michigan Central, Consolidation type, cross-compound, wide fire-box.
No. 4, Atchison, Topeka & Santa Fe, Santa Fe type, tandem compound, (decapod with trailer).
No. 5, Pennslvania Railroad, Atlantic type, 4 cylinder balanced compound, (De Glehn).
No. 6, Atchison, Topeka & Santa Fe, Atlantic type, 4 cylinder balanced compound.
No. 7, Hanover Locomotive Works, Atlantic type, 4 cylinder balanced compound, with superheater.
No. 8, New York Central & Hudson River, Atlantic type, 4 cvlinder balanced compound.

No. 9, Henschel & Sohn, 3 cylinder compound.
No. 10, Pennsylvania Railroad, Atlantic type, simple, "D" valves.
No. 11, Michigan Central, Pacific type, simple, drivers 75 inches diameter.
No. 12, New York Central & Hudson River, Atlantic type, simple, piston valves.

Later it was found impossible to test more than eight locomotives and, therefore, the owners of the last three were advised that their locomotives would not be required; the representative of Henschel & Sohn having already withdrawn their locomotive from the tests.

The locomotives tested comprised simple, two-cylinder cross compound, four-cylinder tandem and four-cylinder balanced compound types.

The range of dimensions of boilers was as follows:
Grate area, square feet..........................from 29 to 58
Heating surface (calculated on fire side of
tubes), square feet........................from 1753 to 4306
Ratio of grate area to heating surface....from 1 to 50 to 1 to 79
Length of tubes, feet.......................from 13.7 to 19.9

Of the four-cylinder balanced compound locomotives, the De Glehn and the New York Central had direct connection to both driving axles, while the Atchison and Hanover locomotives had all main rods connected to the front driving axle.

The owners of the locomotives selected for test were requested to prepare the locomotives in accordance with a circular covering the following important points:

The dynamometer for the testing plant being designed for a variation of draw-bar height ranging from 30 inches to 42 inches, measured from top of rail to center of draw-bar, locomotives on which this dimension did not fall between these limits could not be tested.

Locomotives were required to be in thoroughly good condition and to have been in service on the road a sufficient time to bring all bearings to a good fit, so that trouble from heating of parts would not interrupt the tests.

Boilers were required to be tested, cleaned and staybolts examined.

The valves were to be set in accordance with the approved practice under road conditions, and information as to the setting furnished, so that it could be restored in case of derangement.

Particular attention was to be given to eliminating lost motion in the valve gear.

Each company sending a locomotive was asked to furnish a machinist familiar with its construction, and if they so elected, an engineman of their own selection.

A complete set of working prints was to be furnished.

For reproduction in the report of tests it was asked that a set of special tracings, in accordance with the list given below, be prepared; the location of instruments being shown on the general arrangement.

In addition to the list of tracings given, any special and peculiar features which might effect the economy of the locomotive, were to be shown on similar drawings:

General arrangement
Boiler
Grates
Superheater
Stack
Steam pipes
Cross sections
Valve motion
Ash pan
Front end arrangement
Throttle valve
Dry pipe
Exhaust base and nozzle.

The coupling pin hole in the foot plate and draw-bar was required to be drilled or reamed and the pin turned to fit, as it was absolutely essential to prevent the locomotive moving from its position on top of the supporting wheels.

The draw-bar was to be forged solid without welds, the length depending upon the distance from center of coupling pin hole to back of foot-plate, plus the constant distance from back of foot-plate to threaded end.

Attachments were required on foot-plate of equal strength with safety bars, and safety bars of proper length and size from attachment to turn-buckle.

Safety chains could not be used.

Indicator reducing motions for each cylinder were to be furnished by the owner.

It was asked that means be provided for oiling driving boxes of locomotives while in motion.

In case of locomotives provided with receivers it was required that pipes leading to the side of the locomotive, with standard connection for steam gauges, from each receiver, be provided.

The openings in cylinder and port cocks, through which steam was allowed to escape, were to be tapped, so that pipes could be attached to carry off the steam and water.

Locomotives were to have glass water gauges and automatic cylinder lubrication.

The following parts were required to be furnished to facilitate repairs:

A set of rod bushings for one side.

A set of main rod brasses for one rod.

A set of tools for locomotive.

A set of wrenches for locomotive, including any special wrenches, such as rod wrenches, pop valve wrenches, etc.

Extra glasses for glass water gauge.

" " " automatic lubricator.

Cylinder packing rings.

Valve packing rings or strips.

Piston rod packing.

Valve " "

CHAPTER XI.

INSTALLATION AND PRELIMINARY OPERATION OF THE PLANT.

Excavations for the foundations were begun January 15th, 1904, the foundations, which were of concrete, being completed March 1st, about six weeks later than was expected. The delay was caused by unfavorable weather and bad roads which made hauling of materials difficult and slow.

The erection of the runway for the crane was completed March 1st, and the crane was put in position March 3rd.

The installation of the bed plates and the dynamometer housings was completed March 25th.

In order to carry the weight of the stack it became necessary to strengthen the roof trusses of the building and erect additional trusses for the runway of the stack truck.

Provision was made for a small repair shop, as on account of the location of the testing plant being so isolated it was impossible to get the necessary fitting of parts and repairs made in any regular shop.

A 20 in. x 12 ft. screw cutting lathe, a 24 in. shaper, a 36 in. drill press, a 36 in. grind-stone and a full equipment of hand tools were obtained and installed in the booth immediately behind the testing plant.

As it was necessary to make analyses of the coal and flue gases, and calorimeter determinations of the calorific value of the coal, cinders and sparks for each test, a chemical laboratory equipped for the determination mentioned was installed in one end of the repair shop.

The dynamometer weighing mechanism arrived April 25th, having been delayed two months by reason of unexpected difficulties encountered in its construction. It was placed in the housings, the pedestals, supporting wheels and other parts were put in position and the plant pronounced ready for operation on May 4th.

On the same day Pennsylvania Railroad locomotive No. 1499 was placed upon the plant and the preliminary running began.

While the plant was being gradually brought to working conditions, the observers were trained in their respective duties.

This preliminary running and education of force consumed a period of twenty-one days; the first regular test of the locomotive named being made May 25th.

CHAPTER XII.

INTERRUPTIONS AND DELAYS.

SUPPORTING AXLES AND BEARINGS.

The bearings were made of "Plastic Bronze," the caps of cast iron and as originally made the boxes were provided with chain oilers. The clearance between the journal and cap was very small and this with the inefficiency of the chain oilers at low speeds resulted in serious damage to one journal.

As an extra precaution against heating oilers were stationed in the pit, each one having charge of two boxes, the movement of the oil chains was closely watched, and the temperature of the parts observed, but the difficulties with heating continued.

An oil cup was then located at the center of each cap, oil grooves were chipped in the bushings and caps, and the shape of the bushings was altered by tapering off the top edges which might have tended to scrape the oil from the surfaces of the journals.

These alterations not having entirely eliminated trouble from heating the method of lubrication was changed, the oil chains being removed, the chain slots closed, and two additional oil cups were placed on the cap; the boxes as altered being shown in Fig. 18. This change greatly reduced the difficulties from heating. The only further trouble experienced from this cause was with locomotives which were not well counterbalanced, when the variations in pressure on the supporting wheels tended to close the bushings on the axles and so caused heating.

Engine oil was originally used in these boxes, but after a series of experiments it was found that a mixture consisting of one half engine oil, one quarter lard and one quarter paraffine oil gave the best results. The lard oil was introduced because it smoked at a much lower temperature than the other oils and gave visible warning when heating took place.

WATER PRESSURE.

The water pressure for operating the Alden brakes was obtained from the mains of the City of St. Louis, and was subject to sudden and violent fluctuations in pressure, which sometimes amounted to 50 pounds in three seconds, causing the locomotive to race or stall, and frequently stopping the supporting wheels.

When this occurred, flat spots were made on the supporting wheels which took several days to remove by grinding.

To overcome the fluctuations due to water hammer, a thin diaphragm having a 4 inch aperture was installed in the 6 in. supply pipe immediately below the control valve, and an air chamber of 5 cubic feet capacity was installed above the diaphragm. These appliances had a beneficial effect, decreasing the intensity of the water hammer, but not eliminating it. Later, the size of the air reservoir was increased to 20 cubic feet, which further decreased the trouble from water hammer ,but the fluctuations in pressure were still so serious that the automatic devices installed for controlling variations in speed proved inadequate.

The resistance to the turning of the supporting wheels on which the speed of locomotive depended had to be controlled by detailing a man to manipulate the hand control valve, in accordance with the varying water pressure.

An adequate and permanent remedy for this difficulty was not provided because of the temporary location of the plant at the Exposition, and the difficulty of making any permanent change during the period of the Exposition.

LACK OF ADHESION BETWEEN DRIVING WHEELS AND SUPPORTING WHEELS.

Clearly the area of surface contact between two wheels is very much less than that between a wheel and a rail; also in the plant the driving wheels traveled repeatedly over the same surface of support, which for unavoidable reasons became worse and worse from oil and water dropping on it, while on the track the driving wheels are always traveling over a fresh surface.

Possibly also the rigidity of the support for the locomotive had some influence on the adhesion; but if so, it was probably not an important one.

When a locomotive was operated on the testing plant, the steam which escaped from cylinder cocks, piston rod packings, etc., carried with it some vaporized oil. Both the steam and oil condensed the moment they came in contact with the cold surfaces of the driving and supporting wheels, and a film of oil and water was formed on the tires of both wheels. In this way the adhesion was reduced, and slipping of the drivers took place and caused flat spots on the supporting wheels. To overcome this, sheet iron covers were placed over the supporting wheels, and a force of men was constantly employed in wiping the wheels with cotton waste, alternating with emery cloth to insure as clean surfaces as possible.

On two occasions the driving wheels slipped when wires for counterbalance tests were being passed under the wheels; after this occurred no more wires were run through at speeds less than 200 r. p. m.

ALDEN BRAKES.

The brake housings were kept from turning by two tie bars, and in order to prevent the weight of the housing from resting on the brake hub it was necessary to adjust the tie bars so as to support the housing and still avoid its pressing against the hub from below and as the clearance between the hub and housing was only sufficient for a running fit; the adjustment, had to be extremely accurate to avoid heating.

Originally engine oil was used to lubricate the brakes, but it was found to be somewhat too fluid for the purpose, and that valve oil, having greater viscosity, was not only more difficult to squeeze out from between the surfaces, but would also give the same retarding effect with less water pressure, than engine oil. Following this same line, an oil of still greater viscosity than valve oil was used; the best mixture being seven-eighths valve oil to one-eighth castor.

About half way through the total period of testing, one of the brakes was found to have a badly cracked disc; fortunately, no other damage was done, the injury probably being detected very soon after the break occurred.

DYNAMOMETER.

The greater part of the time consumed on account of the dynamometer was due to recalibrations that were made.

The machine efficiency of the first two locomotives, although similar in type and dimensions of running gear, differed so materially that it was feared the dynamometer was not giving correct indications. It was, therefore, recalibrated by using the Pennsylvania Railroad dynamometer car; the car dynamometer was also recalibrated and the recalibration repeated with satisfactory results.

When an attempt was made with the first freight locomotive tested, to run at 240 revolutions, it was found that at 176 revolutions the whole locomotive moved forward and backward on the supporting wheels; this change from pull to push and back again being due to the horizontal component of the unbalanced reciprocating parts, and the lowest speed at which it could be detected was called the "critical speed."

The dynamometer was constructed so that both push and pull were recorded on the same side of the datum or zero line. To change from a pull to a push the pull pen must return to the datum line, and as the strain reversed nearly 180 times a minute the inertia of the parts made this impossible.

This discovery made necessary the introduction of dash-pots in the safety bars, which are described on page 34.

FIRING.

While no time was lost on account of difficulties in firing, this work imposed at all times a severe task on the fireman. This will be realized when it is considered that he often had to fire continuously for three hours and maintain approximately the maximum steam pressure. The fireman did not have the benefit of the short periods of rest on the testing plant which are afforded him when descending grades on the road, and of other causes which bring him occasional relief. In some of the tests the weight of coal fired amounted to 6700 pounds per hour. Two firemen had to be provided, notwithstanding which when hot weather came the fireman on one occasion fainted and became ill from exhaustion. It was found necessary to procure and install a fan to furnish a plentiful supply of air to the cab, and discharge pipes were also provided for the computing room. This fan afforded great relief, not only to the fireman, but to the other members of the force engaged in making observations, as well as to the computers.

In the last month of the tests the work became so heavy that a third fireman was necessary.

The first official test was made on May 25th and the operation of the plant closed December 3rd—a period of 193 days—during which time 104 tests were made.

The following analysis of the time shows what proportion of it was lost on account of difficulties already referred to and for other causes:

Testing	52	days.
Lost on account of hot supporting axle boxes	22.5	"
" " " " water pressure, flat spots on supporting wheels	14.5	"
" " " " dynamometer	10	"
" " " " miscellaneous, due to plant	5.5	"
" " " " hot parts on locomotives	16.5	"
" " " " locomotives not steaming	5	"
" " " " attachments and repairs to locomotives	10.5	"
" " " " changing locomotives	9	"
" " " " miscellaneous, due to locos	2.5	"
" " " " waiting for shifts	11	"
" " " " holidays and Sundays	32	"
" " " " miscellaneous	2	"
	193	days.

The analysis of time consumed has been made on the assumption that each test required one half day. As 104 tests were made in all it is stated that 52 days were spent in testing, while as a matter of fact one or more tests were obtained on 80 days.

CHAPTER XIII.

TESTS OF CONSOLIDATION LOCOMOTIVE, PENNSYLVANIA RAILROAD COMPANY.

The first locomotive placed on the testing plant was No. 1499 owned by the Pennsylvania Railroad Company. It is of the simple consolidation (2-8-0) type, and is the standard heavy freight locomotive used on the Pennsylvania Railroad. It is known as the "H6a" type according to the railroad company's classification. The locomotive was new and had not been thoroughly broken in before being tested. The first official test was made on May 25th, the locomotive having been run previously for three weeks in order to break in the plant. The principal dimensions and details of the locomotive are given in Appendix 100. The principal nominal dimensions are shown in the following table:

Total weight, lbs.	194,200
Weight on drivers, lbs.	173,200
Cylinders (simple), inches	22x28
Diameter of drivers, inches	56
Fire-box heating surface, sq. ft.	166.4
Heating surface in tubes (water side) sq. ft	2,677.27
Total heating surface (based on water side of tubes) sq. ft.	2,843.67
*Total heating surface (based on fire side of tubes) sq. ft.	2,482.26
Grate area, sq. ft.	49.2
Boiler pressure, lbs.	205
Valves	Richardson balanced.
Link motion	Stephenson.
Fire-box, type	Belpaire.

---

* Used in Calculations.

No. of tubes	373
Outside diameter of tubes, inches	2
Length of tubes, inches	164.5

The maximum tractive effort was 39,773 pounds, which was calculated on the assumption that 80 per cent. of the boiler pressure (205 pounds) was available as mean effective pressure at starting. On this basis the ratio of weight on drivers to maximum tractive effort was 4.35:1.

TESTS.

The tests which have been run, together with the laboratory designations and dates of running, are as follows:

Test No.	Laboratory. Designation.	Date.
101	160-40-P	June 11th
102	160-20-F	" 7th
103	80-20-F	May 25th
104	160-45-P	June 10th
105	160-27-F	" 9th
106	160-34-F	" 8th
108	80-40-F	" 15th
109	80-20-F	" 4th
110	40-20-F	" 16th
111	40-30-F	" 18th
112	80-30-F	" 20th
113	160-30-F	" 20th
114	160-50-P	" 21st
115	120-35-F	" 21st
116	120-30-F	" 22nd
117	160-35-P	" 22nd
118	80-37-F	" 24th

In the laboratory designation the first figure indicates the approximate speed in revolutions per minute, the second figure indicates the approximate cut-off in per cent., high pressure cylinder, and the letter indicates the position of the throttle valve, whether fully open (F) or partly open (P).

Owing to evident inconsistencies, shortness of tests, etc., the results obtained from tests Nos. 104, 106, 108, 113 and 114 have not been plotted on the diagrams, but the data for these tests will be found with the other data in Appendix 100. Some of these tests determine the maximum boiler power.

The performance of a locomotive naturally divides itself into three parts relating separately to the boiler, the engines, and the locomotive as a whole.

As already outlined, the performance of this and the other locomotives which have been tested, will be considered under the several heads as above noted.

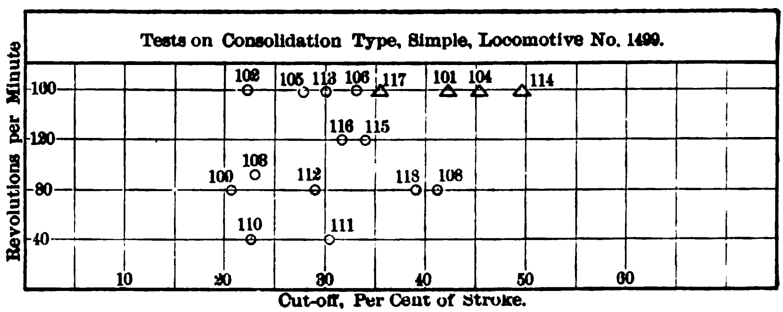


Fig. 101.

In the following discussions the headings of the columns are self explanatory. The number at the head of each column of the tables corresponds with the number used in the tables of recorded data shown in full in the Appendix. When no number is used, the column represents items calculated from the recorded data.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 101.

The tests are arranged in order, according to the rate of equivalent evaporation. It will be noted that no recorded test was shorter than 130 minutes, while the longest was 210 minutes.

The lowest average boiler pressure was 176.9 pounds, while the highest was 203.4 pounds. In general, however, the variations of average pressure did not exceed 5 per cent. The temperature of the feed water was very uniform. In the majority of tests more than 150 pounds of coal per square foot of grate were fired. Only two of the tests fell below 100 pounds. The total coal fired per square foot of grate area follows:

In 2 tests ....between 100 and 150 lbs.
In 2 tests ....between 150 and 200 lbs.
In 5 tests ....between 200 and 250 lbs.
In 1 test ....more than 250 lbs.

TABLE No. 101—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. of Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
110	40-20-F	150	200.4	14.50	75.9	73.9	57.2
111	40-30-F	180	203.4	14.46	72.5	73.8	84.3
109	80-20-F	200	191.6	14.37	70.7	67.1	143.0
103	80-20-F	180	197.6	14.41	78.8	63.7	129.4
112	80-30-F	180	200.7	14.45	74.1	74.0	170.5
102	160-20-F	210	189.3	14.49	71.1	67.4	234.6
105	160-27-F	180	181.6	14.55	70.3	70.9	235.3
116	120-30-F	180	198.7	14.50	73.6	73.0	216.3
118	80-37-F	180	201.4	14.51	82.2	74.2	212.7
101	160-40-P	180	176.9	14.50	73.5	72.5	261.7
115	120-35-F	180	193.1	14.44	78.1	73.4	248.9
117	160-35-P	130	201.8	14.48	78.6	73.5	184.9

TABLE No. 102—EVAPORATION.

Identification of Test		Duration of Test, Minutes	Water and Steam		Calorimeter Results			Equivalent Evaporation Lbs. Per Hour
Test Number	Laboratory Designation		Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Quality of steam in Branch Pipe	Degrees Superheat in Branch Pipe	
		Cal.	264	340	*228	229	230	344
110	40-20-F	150	27071	10828	.9884	.9964	0	12870
111	40-30-F	180	38744	12915	.9903	.9918	0	15372
109	80-20-F	200	51219	15381	.9882	——	—	18375
103	80-20-F	180	51586	17195	.9889	.9927	0	20581
112	80-30-F	180	57620	19207	.9886	.9924	0	22825
102	160-20-F	210	71546	20442	.9887	.9972	0	24410
105	160-27-F	180	69344	23114	.9894	.9977	0	27518
116	120-30-F	180	70355	23452	.9882	.9913	0	27856
118	80-37-F	180	70969	23656	.9883	.9953	0	28102
101	160-40-P	180	71855	23785	.9899	1.0109	19.74	28203
115	120-35-F	180	75575	25192	.9885	.9917	0	29900
117	160-35-P	130	56115	25896	.9877	.9858	0	30747

*Item 228 is not used in finding item 344; item 231 (see appendix) being used to obtain dry steam.

EVAPORATION—TABLE 102.

The evaporation per hour was between the limits of 10,828 pounds and 25,896 pounds.

The quality of steam in the steam dome was obtained by means of a throttling calorimeter and it is of interest to note that it was uniformly high, the moisture never exceeding 1¼ per cent. By glancing down the column, however, it will be seen that there was no obvious relation between the increase in moisture and the increase in the rate of evaporation.

The quality of steam in the branch pipe at a point close to the steam chest was, of course, dependent somewhat on cylinder conditions and particularly on the position of the throttle valve. The superheat of 19.74 degrees in the branch pipe in test No. 101 was due to the fact that the throttle was only partly open.

The equivalent evaporation per hour from and at 212 degrees Fahr. is an accurate measure of the work done by the boiler and gives a convenient unit for making comparisons.

BOILER POWER—TABLE 103.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 262 to 625.

The equivalent evaporation per square foot of heating surface ranged from 5.18 to 12.39 pounds per hour.

The maximum boiler horse power developed was 891.3, the horse power being calculated on the usual basis of 34.5 evaporative units per horse power.

The horse power developed per square foot of heating surface ranged from .150 to .359.

The maximum horse power developed per square foot of grate surface is equivalent to about one horse power for each .055 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 104.

When large quantities of coal are consumed the error introduced by a variation in the condition and thickness of the fire at the beginning and at the end of a test is less important than in tests where smaller quantities are used, but great care was exercised in all cases to eliminate, as far as possible, this source of error. The total coal fired ranged from 2,790 pounds to 12,755 pounds, and the amount per hour from 1,116 pounds to 4,252 pounds.

The dry coal fired per square foot of grate area per hour

TABLE No. 103—BOILER POWER.

Identification of Test		Duration of Test, Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft. of Grate Surface
		Cal.	Cal.	345	319	Cal.	Cal.
110	40-20-F	150	262	5.18	378.0	.150	7.58
111	40-30-F	180	312	6.19	445.5	.179	9.05
109	80-20-F	200	373	7.40	532.6	.215	10.82
108	80-20-F	180	418	8.29	596.5	.240	12.12
112	80-30-F	180	464	9.20	661.6	.267	13.44
102	160-20-F	210	496	9.83	707.5	.285	14.38
105	160-27-F	180	559	11.08	797.5	.321	16.21
116	120-30-F	180	566	11.22	807.4	.325	16.41
118	80-37-F	180	571	11.32	814.6	.328	16.55
101	160-40-P	180	573	11.36	817.5	.329	16.61
115	120-35-F	180	608	12.04	866.7	.349	17.61
117	160-35-P	130	625	12.39	891.3	.359	18.12

TABLE No. 104—COAL AND RATE OF COMBUSTION.

Identification of Test		Duration of Test, Minutes	Total Dry Coal Fired	Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation			Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq. Ft. of Grate Per Hour	Dry Coal Per Sq. ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
110	40-20-F	150	2790	2590	1116	1036	22.7	.450
111	40-30-F	180	4104	3808	1368	1269	27.8	.551
109	80-20-F	200	6980	6186	2094	1858	42.6	.844
108	80-20-F	180	6268	5818	2089	1939	42.4	.842
112	80-30-F	180	8301	7779	2767	2593	56.2	1.115
102	160-20-F	210	11450	10148	3271	2899	66.5	1.318
105	160-27-F	180	11486	10701	3829	3567	77.8	1.542
116	120-30-F	180	10547	9340	3516	3113	71.5	1.416
118	80-37-F	180	10344	9576	3448	3192	70.1	1.389
101	160-40-P	180	12755	11901	4252	3967	86.4	1.713
115	120-35-F	180	12122	11233	4041	3744	82.1	1.628
117	160-35-P	130	9021	8326	4163	3842	84.6	1.677

ranged from 22.7 pounds to 86.4 pounds, showing the intensity of the furnace action. It will be noted that the increase in the rate of combustion was not regular.

The coal burned per square foot of heating surface per hour ranged from .450 to 1.713 pounds.

CINDERS AND SPARKS—TABLE 105.

This table is significant only in a general way, as it was found that a good many sparks escaped from the spark trap and were carried away.

The maximum calorific value of the cinders was 11,224 B. T. U., and the maximum calorific value of the sparks was 9,024 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 106.

In Fig. 102 are plotted the draft pressures as shown in Table 106. The ordinates represent draft, while the abscissae represent rates of combustion.

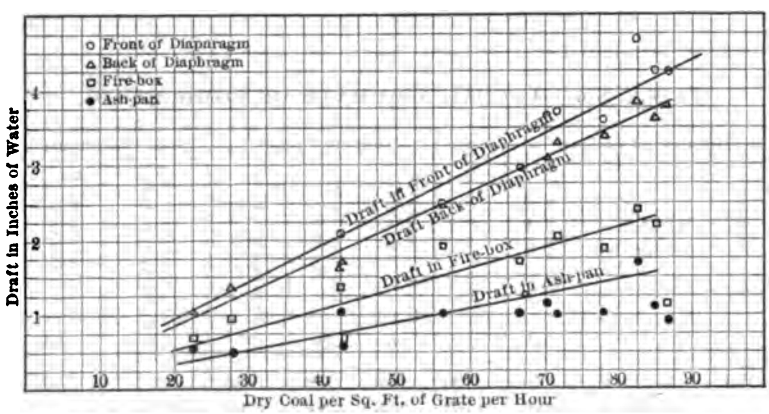


Fig. 102.— Draft and Rate of Combustion.

The straight lines which have been drawn do not represent absolutely the draft pressures which were observed, but the lines are approximately correct. They are given principally to show the relative amount of draft required to overcome the several resistances encountered by the air in its passage from the ash-pan to the smoke-box. The air openings in the ash-pan of this locomotive were rather small,

TABLE No. 105—CINDERS AND SPARKS.

Identification of Test		Duration of Test, Minutes	Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation		Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
110	40-20-F	150	74.0	34.0	108.0	11004	7483
111	40-30-F	180	44.3	24.0	68.3	8363	7268
109	80-20-F	200	101.0	29.7	131.2	——	——
103	80-20-F	180	40.0	38.3	78.3	——	——
112	80-30-F	180	204.0	39.6	243.6	10564	7923
102	160-20-F	210	278.0	81.7	359.7	11158	8772
105	160-27-F	180	362.6	156.0	518.6	10454	8584
116	120-30-F	180	407.0	105.0	512.0	10684	8033
118	80-37-F	180	255.0	64.0	319.0	11005	9024
101	160-40-P	180	424.0	227.0	651.0	9464	7813
115	120-35-F	180	482.3	127.3	609.6	10784	7923
117	160-35-P	180	385.3	107.0	492.3	11224	9024

TABLE No. 106—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water				Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft. of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In front of Diaphragm	Back of Diaphragm	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	223	224	225	212	207	339
110	40-20-F	150	——	1.05	.70	.56	1427	561	22.7
111	40-30-F	180	——	1.36	.95	.51	1480	581	27.8
109	80-20-F	200	——	1.70	.68	.59	1658	565	42.6
103	80-20-F	180	2.08	1.63	1.37	1.03	1662	562	42.4
112	80-30-F	180	2.50	2.46	1.91	1.03	1742	656	56.2
102	160-20-F	210	2.94	2.74	1.71	1.03	2028	654	66.5
105	160-27-F	180	3.59	3.38	1.86	1.03	2112	691	77.8
116	120-30-F	180	3.70	3.28	2.04	1.00	1769	722	71.5
118	80-37-F	180	3.60	3.10	1.28	1.13	1766	685	70.1
101	160-40-P	180	4.21	3.76	1.15	.91	1968	714	86.4
115	120-35-F	180	4.66	3.81	2.42	1.69	2001	724	82.1
117	160-35-P	180	4.25	3.62	2.17	1.09	1821	726	84.6

as indicated by the relatively high reduction of pressure in the ash-pan.

If G represents the rate of combustion in pounds per square foot of grate surface per hour and D represents the draft in

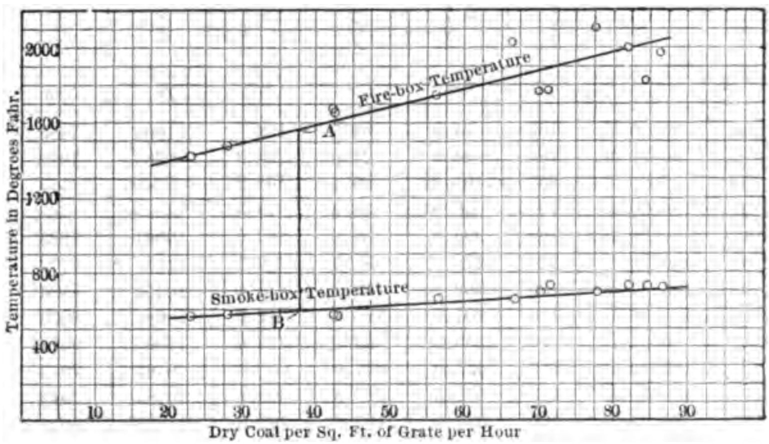


Fig. 103.—Firebox and Smokebox Temperatures.

front of the diaphragm in the smoke-box, then for this locomotive, as shown by the upper line of Fig. 102:

$$D = .049G \qquad (101)$$

This approximate equation means that for every pound of coal burned per square foot of grate per hour, a draft of .049 inches of water was required in the smoke-box.

The temperatures in the fire-box and in the smoke-box were obtained by means of a Le Chatelier pyrometer. Smoke-box temperatures were also obtained by means of a thermometer, both instruments checking closely, as will be seen by referring to the data in the Appendix. Plots 105 and 106 in the Appendix, show the fire-box and smoke-box temperatures respectively for different rates of combustion, the combustion being measured by the total pounds of dry coal fired per hour.

For ease in comparison, Fig. 103 has been plotted, which shows fire-box and smoke-box temperatures on the same diagram, the abscissae being rates of combustion in pounds per square foot of grate per hour.

The fire-box temperatures ranged from 1,427 to 2,112 degrees Fahr. and the smoke-box temperatures ranged from 561 to 726 degrees Fahr.

The diagram, Fig. 103, shows that the fire-box temperature increased at a much greater rate than the smoke-box temperature as the rate of combustion increased. In fact, the variations in smoke-box temperatures were within comparatively small limits. The length of the ordinate, such as AB, or the drop in temperature between the two lines on the diagram at any given rate of combustion, represents the drop in temperature of the gases in passing from the fire-box to the smoke-box This heat has been absorbed by the heating surface of the boiler and should bear some relation to the rate of evaporation. The relation which exists is determined as follows:

Let;

H=Equivalent rate of evaporation in pounds per square foot of heating surface per hour.

G=Rate of combustion in pounds per square foot of grate per hour.

T_f=Temperature in fire-box in degrees Fahr.

T_s=Temperature in smoke-box in degrees Fahr.

Then $T_f - T_s$ represents the drop in temperature of the gases in passing from the fire-box to the smoke-box.

From Fig. 103 the relation betveen T_f and G is found to be for this locomotive:

$$T_f = 9.6\ G + 1210 \quad \text{(102)}$$

Similarly, the relation between T_s and G is found to be

$$T_s = 2.44\ G + 500 \quad \text{(103)}$$

Then the drop in temperature is determined by subtracting (103) from (102) which gives

$$T_f - T_s = 7.16\ G + 710 \quad \text{(104)}$$

The relation existing between G and H is plotted in Fig. 104, from which

$$H = .113G + 2.9 \quad \text{(105)}$$

From equation (104)

$$G = .140\ (T_f - T_s) - 99.1 \quad \text{(106)}$$

From equation (105)

$$G = 8.85H - 25.7 \quad \text{(107)}$$

Equating equations (106) and (107) and reducing gives:

$$H = .016\,(T_f - T_s) - 8.29 \qquad (108)$$

By the use of equation (108) the rate of evaporation can be determined if the temperatures of the fire-box and smoke-box are known. Similarly, the rate of combustion can be found

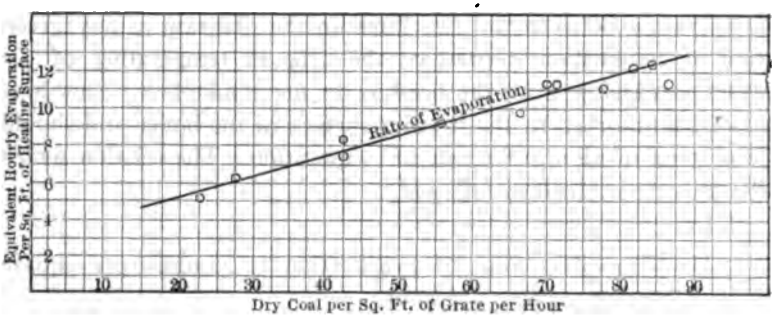


Fig. 104.— Rates of Combustion and Evaporation.

from equation (105) if the rate of evaporation is known, or vice-versa.

EVAPORATIVE PERFORMANCE—TABLE 107.

The equivalent evaporation per pound of dry coal ranged from 11.53 pounds to 6.63 pounds.

The heating value of the coal was practically uniform for all the tests.

The efficiency of the boiler dropped rapidly as the rate of evaporation increased, the range being between the rather wide limits of 78.93 per cent. and 45.37 per cent.

In the Appendix, Plots 101, 102, 104, 109, 110 and 111, show relations existing between the factors given in Table 107 and other factors already presented in previous tables. But for the purpose of obtaining an equation between rate of evaporation and evaporation per pound of dry coal, Fig. 105 has been plotted.

Let G=the rate of combustion in pounds per square foot of grate per hour, then from equation (105) H, the rate of evaporation per square foot of heating surface per hour, can be found and by the substitution of this value of H in the following equation, derived from Fig. 105, E, the equivalent pounds of water evaporated per pound of dry coal can be determined.

$$E=15-.66H \qquad (109)$$

While all the equations which have been derived do not represent every experimental result which has been obtained, they

TABLE No. 107—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
110	40-20-F	150	9.61	11.58	12.42	14109	78.98
111	40-30-F	180	9.34	11.24	12.11	14018	77.45
109	80-20-F	200	7.28	8.78	9.90	13482	59.92
108	80-20-F	180	8.10	9.85	10.61	14144	67.25
112	80-30-F	180	6.87	8.25	8.80	14242	55.94
102	160-20-F	210	6.19	7.46	8.42	13482	48.40
105	160-27-F	180	5.98	7.19	7.71	14755	47.04
116	120-30-F	180	6.61	7.92	8.95	13769	55.57
118	80-37-F	180	6.78	8.15	8.80	14809	53.15
101	160-40-P	180	5.54	6.63	7.11	14119	45.37
115	120-35-F	180	6.17	7.40	7.99	14124	50.59
117	160-35-P	180	6.17	7.39	8.00	14651	48.69

will, nevertheless, serve as a convenient and logical basis upon which comparisons can be made.

SMOKE-BOX GASES—TABLE 108.

While the percentage of oxygen showed some irregularities, nevertheless there was a tendency for it to decrease as the rate of evaporation increased—the range for the several tests being between the limits of 7.40 per cent. and 2.20 per cent.

The percentage of CO increased as the rate of evaporation increased—the range for this locomotive being between the limits oi .07 per cent. and 4.53 per cent.

The carbon dioxide, CO_2, ranged from 9.75 per cent. to 13.03 per cent.

The calorific value of the coal as fired is of interest chiefly in connection with the last column of Table 108, which gives the per cent. of heat lost by imperfect combustion due to the fact that part of the carbon is burned to CO instead of CO_2.

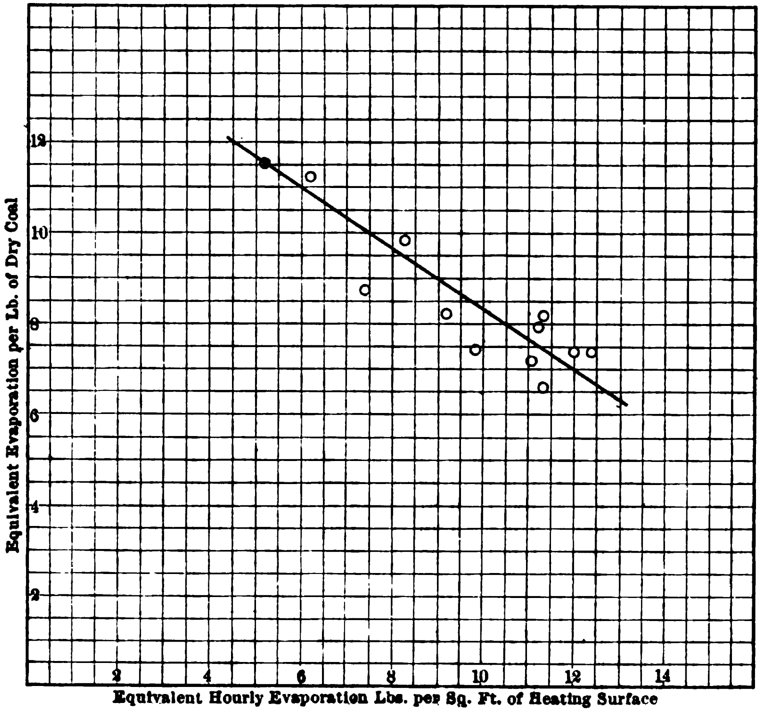


Fig. 105.— Rate of Evaporation and Evaporation per Lb. of Coal.

The method of determining the items in this column is as follows:

Let;

A=per cent. of CO in smoke-box gases.

B=per cent. of CO_2 in smoke-box gases.

C=per cent. of carbon in fuel (determined by an ultimate analysis to be 84.20%).

D=calorific value of fuel as fired in B. T. U.

10,150=B. T. U. lost in burning one pound of carbon to CO instead of CO_2.

P=per cent. of heat lost in coal as fired due to presence of CO.

Then;

$$\frac{\left\{\frac{A}{A+B}\right\} \times C \times 10150}{D} = P \quad \ldots\ldots\ldots\ldots\ldots\ldots (110)$$

The heat lost by imperfect combustion ranged from .33 per cent. to 16.33 per cent.

TABLE No. 108—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
110	40-30-F	150	7.40	.07	11.70	80.83	13976	.36
111	40-30-F	180	5.96	.07	12.90	81.07	13866	.33
109	80-30-F	200	6.00	1.08	11.97	80.95	13315	5.31
103	80-30-F	180	5.38	1.40	12.15	81.07	13920	6.34
112	80-30-F	180	3.33	2.57	12.40	81.70	14036	10.42
102	160-30-F	210	4.44	1.13	13.03	81.40	13315	5.12
105	160-27-F	180	5.07	1.63	11.73	81.57	14636	7.12
116	120-30-F	180	3.67	3.30	12.23	80.80	13646	13.31
118	80-37-F	180	3.60	4.13	11.70	80.57	14636	15.23
101	160-40-P	180	3.17	2.93	11.67	82.23	13976	12.27
115	120-35-F	180	2.20	4.53	12.43	80.84	13976	16.33
117	160-35-P	130	6.90	2.25	9.75	81.10	14526	11.03

PERFORMANCE OF ENGINES.

The results in Tables 109 and 110 are arranged with reference to the speed of the locomotive, the tests at each speed being grouped. The tests in each group are arranged with reference to the nominal cut-off in the cylinders, the first test in each group being at the shortest cut-off and the last test being at the longest cut-off.

GENERAL ENGINE CONDITIONS—TABLE 109.

This table is self-explanatory. The actual revolutions per minute approximated closely to those selected for each test. The actual per cent. of cut-off varied somewhat from the nominal,

TABLE No. 109—GENERAL ENGINE CONDITIONS.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke	Steam Pressure: In Boiler Lbs. Per Sq. In.	Steam Pressure: In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	217	220
110	40-20-F	150	40.33	6.70	22.44	200.4	———
111	40-30-F	180	40.42	6.72	30.45	203.4	202.4
103	80-20-F	180	92.74	15.40	22.80	197.6	197.3
109	80-20-F	200	81.59	13.55	20.88	191.6	———
112	80-30-F	180	79.73	13.24	29.24	200.7	199.6
113	80-37-F	180	80.69	13.40	39.34	201.4	194.6
116	120-30-F	180	120.12	19.95	31.33	198.7	195.7
115	120-35-F	180	120.63	20.04	33.96	193.1	188.2
102	160-20-F	210	160.33	26.63	22.16	189.3	187.4
105	160-27-F	180	157.64	26.20	28.03	181.6	169.4
117	160-35-P	180	160.63	26.68	35.30	201.8	165.4
101	160-40-P	180	160.50	26.66	42.14	176.9	110.9

TABLE No. 110—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch	Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
		Cal.	Cal.	379	381
110	40-20-F	150	85.76	365.7	28.33
111	40-30-F	180	106.34	454.5	27.29
103	80-20-F	180	66.33	650.0	25.51
109	80-20-F	200	68.12	587.6	25.31
112	80-30-F	180	92.42	779.3	23.92
113	80-37-F	180	108.99	930.5	24.70
116	120-30-F	180	76.75	975.1	23.43
115	120-35-F	180	81.22	1036.1	23.74
102	160-20-F	210	47.36	803.3	24.78
105	160-27-F	180	57.09	951.4	23.73
117	160-35-P	180	60.27	1023.7	24.69
101	160-40-P	180	50.23	851.7	27.30

but was as close as could be obtained with the spacing of the notches on the reverse lever quadrant.

The lowest speed at which any test was run was 6.7 miles per hour, while the highest speed was 26.68 miles per hour.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 110.

The significance of the mean effective pressure, the total indicated horse power and the steam consumption, respectively, for

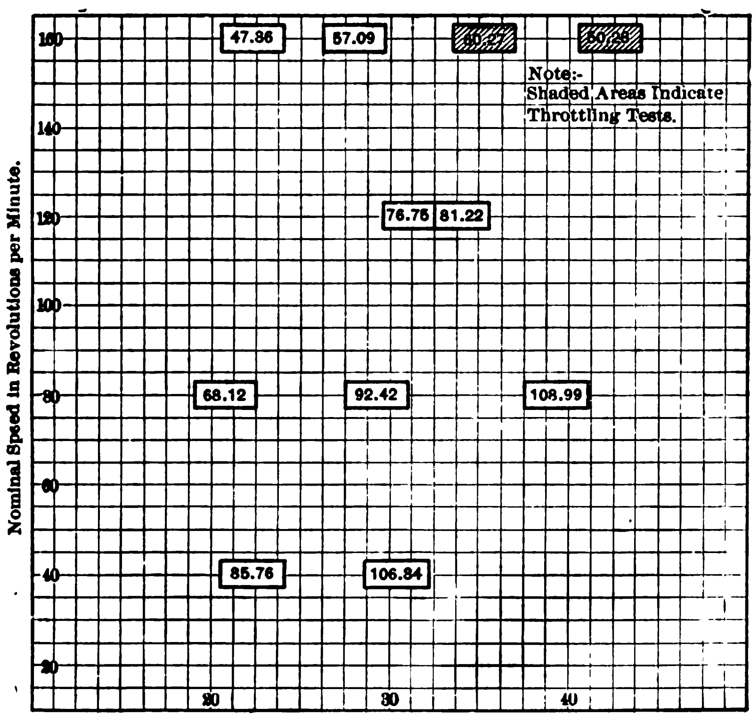


Fig. 106.— Mean Effective Pressure.

the several cut-offs and speeds is best shown by reference to Figs. 106, 107 and 108. In these diagrams the horizontal scale represents the cut-off in per cent. of stroke, while the vertical scale gives the speed of the locomotive in revolutions per minute. The effect of cut-off and speed on mean effective pressure is shown by

Fig. 106. Comparisons along horizontal lines show the effect of increasing the cut-off at constant speed, as for example, at 80 revolutions per minute, at which speed the mean effective pressure was 68.12 pounds, 92.42 pounds and 108.99 pounds at approximately 20, 30 and 40 per cent. cut-off respectively. Comparisons along vertical lines show the effect of changes in speed when the cut-off was nearly constant. For example, at a nominal cut-off of 30 per cent. the mean effective pressure was 106.34, 92.42, 76.75, and 57.09 pounds at 40, 80, 120 and 160 revolutions per minute respectively.

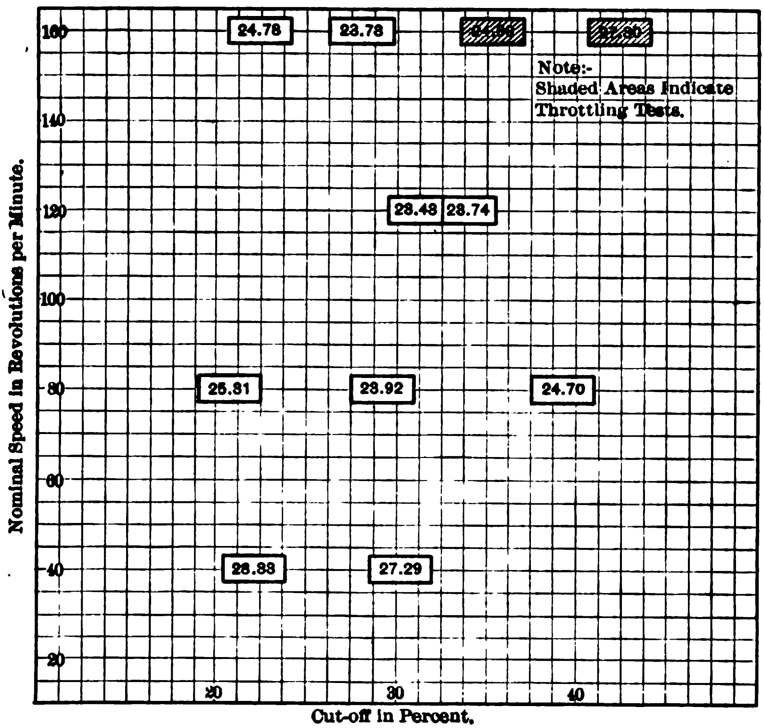


Fig. 107.— Dry Steam per I. H. P. Hour.

The relations between steam consumption, speed and cut-off are shown in Fig. 107. The best performance of the engine was at 31 1-3 per cent. cut-off and 120.12 revolutions per minute (about 20 miles per hour), under which conditions the steam consumption was 23.43 pounds per indicated horse power hour. These relations are also shown by Plot 122 in the Appendix.

It is noticeable that at full throttle tests the differences in steam per indicated horse power hour were small.

The diagram, Fig. 108, shows the relation between indicated horse power, speed and cut-off. The highest indicated horse power was 1,036, which was obtained at 35 per cent. nominal cut-off and a nominal speed of 120 revolutions per minute.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE III.

The performance of a locomotive, taken as a unit, is best measured in terms of draw-bar pull or dynamometer horse power, as these factors determine the usefulness of the machine for hauling cars.

The maximum average recorded draw-bar pull was 22,078 pounds at a nominal speed of 80 revolutions per minute and a nominal cut-off of 37 per cent. Higher draw-bar pulls were not obtained because, at slow speeds and long cut-offs there was constant danger of stalling the brakes and slipping the drivers owing to the fluctuations of the pressure of the water used for controlling the brakes.

The maximum dynamometer horse power was 848.6, which was obtained at a nominal speed of 120 revolutions per minute and a nominal cut-off of 35 per cent.

The general tendency is for the coal per dynamometer horse power hour to increase as the speed increases. The minimum coal rate obtained was 3.54 pounds and the maximum rate was 6.48 pounds per dynamometer horse power hour.

The lowest steam consumption was 28.98 pounds per dynamometer horse power hour, which was obtained at a nominal speed of 120 revolutions per minute and a nominal cut-off of 35 per cent.

MACHINE FRICTION—TABLE 112.

The friction of the mechanism of the locomotive is given in terms of horse power, mean effective pressure, and draw-bar pull respectively. At a given speed, the general law governing the variation of these factors is not apparent. In fact, the machine friction appears to be a constant for any given speed, and for this reason the average value of these items has been worked out for each speed.

The average value of the frictional horse power for nominal speeds of 40, 80, 120 and 160 revolutions per minute was 83.1, 132.5, 187.2 and 224.2 respectively. The average value of the frictional mean effective pressure at nominal speeds of 40, 80, 120, 160 revolutions per minute was 19.47, 15.06, 14.72 and 13.29 pounds respectively. The average frictional draw-bar pull was 4,644, 3,591, 3,511 and 3,171 pounds at nominal speeds of

TABLE No. 111—DYNAMOMETER RECORDS.

Identification of Test		Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D.H.P. Hour
Test Number	Laboratory Designation					
		Cal.	265	383	384	385
110	40-20-F	150	15706	280.6	3.84	36.91
111	40-30-F	180	20864	373.5	3.54	33.21
103	80-20-F	180	12587	517.0	3.94	32.07
109	80-20-F	200	13314	481.2	4.24	30.88
112	80-30-F	180	17831	629.8	4.30	29.59
118	80-37-F	180	22078	789.2	4.28	29.12
116	120-30-F	180	14813	788.1	4.38	28.99
115	120-35-F	180	15883	848.6	4.69	28.98
102	160-20-F	210	8666	615.5	5.22	32.34
105	160-27-F	180	9929	693.5	5.43	32.55
117	160-35-P	130	10902	775.7	5.28	32.58
101	160-40-P	180	9118	648.3	6.48	35.87

40, 80, 120 and 160 revolutions per minute, respectively. These figures disclose the fact that the frictional mean effective pressure and frictional draw-bar pull decrease as the speed increases, which is consistent with the general laws of friction.

The machine efficiency ranged from 72.89 per cent. to 84.82 per cent. In view of the fact that the frictional horse power, frictional mean effective pressure and frictional draw-bar pull are each practically constant for a given speed, it follows that the machine efficiency at a given speed should be expected to increase as the cut-off increases. The results are, in general, consistent with this assumption. For example, at a nominal speed of 40 revolutions per minute and a nominal cut-off of 20 per cent., the machine efficiency was 76.74 per cent. At the same speed, but

TABLE No. 112—MACHINE FRICTION.

Identification of Test		Duration of Test, Minutes	Machine Friction in			Machine Efficiency Per Cent.
Test Number	Laboratory Designation		Horse Power	Mean Effective Pressure Lbs. Per Sq. in	Draw-Bar Pull Pounds	
		Cal.	395	396	397	398
110	40-20-F	150	85.1	19.97	4764	76.74
111	40-30-F	180	81.0	18.97	4524	82.18
	Average		**83.1**	**19.47**	**4644**	
108	80-20-F	180	133.0	13.57	3237	79.54
109	80-20-F	200	106.4	12.35	2944	81.90
112	80-30-F	180	149.5	17.74	4233	80.82
118	80-37-F	180	141.3	16.57	3953	84.82
	Average		**132.5**	**15.06**	**3591**	
116	120-30-F	180	187.0	14.74	3513	80.83
115	120-35-F	180	187.5	14.70	3509	81.91
	Average		**187.2**	**14.72**	**3511**	
102	160-20-F	210	187.8	11.09	2644	76.62
105	160-27-F	180	257.9	15.48	3693	72.89
117	160-35-P	130	248.0	14.61	3485	75.78
101	160-40-P	180	203.4	11.99	2860	76.12
	Average		**224.2**	**13.29**	**3171**	

with a nominal cut-off of 30 per cent., the machine efficiency was 82.18 per cent.

MAXIMUM POWER OF LOCOMOTIVE.

From what has already been said concerning the limitations affecting tests at high draw-bar pulls and speeds, and also from an inspection of the recorded data, it is apparent that it is impossible to construct, directly for this locomotive, a diagram showing the maximum draw-bar pull at all speeds. The importance of such information, however, seems to justify an attempt to construct such a diagram by using the data at hand to establish relations from which the performance of the locomotive can be reasonably determined for conditions beyond the limits of the tests.

In general, the maximum power of a locomotive depends on the relation between the amount of water which can be evaporated by the boiler and the efficiency of the cylinders. For example, if the maximum evaporative power of a locomotive boiler is W pounds of dry steam per hour and the cylinders require N pounds of dry steam per indicated horse power hour, then the maximum indicated power of the locomotive is represented by $\frac{W}{N}$ except that the maximum power may be limited by the adhesion of the driving wheels.

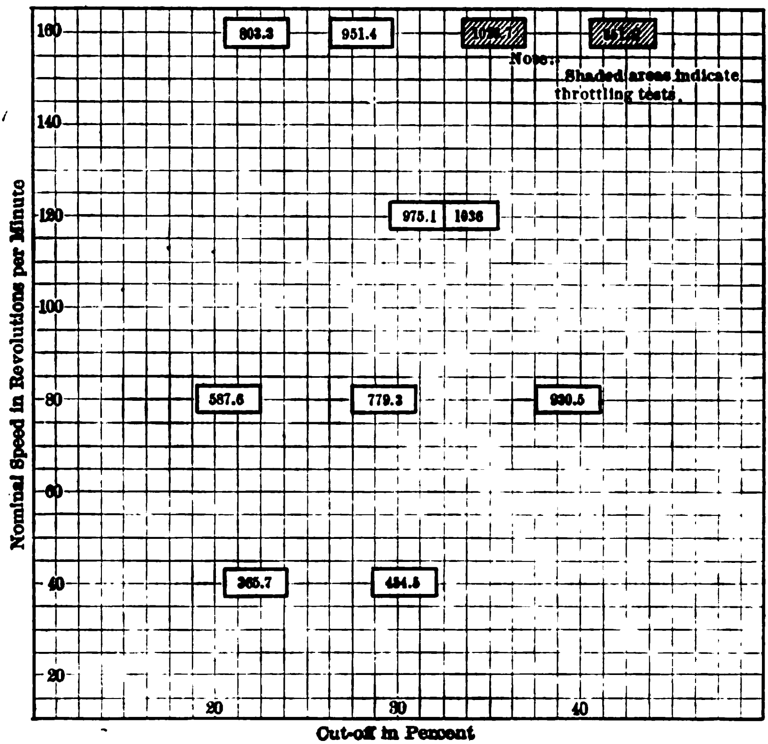


Fig. 108.— Total Indicated Horse Power.

The maximum evaporative power of the boiler, as disclosed by these tests, is between 25,000 and 26,000 pounds of dry steam per hour, which is equivalent to a rate of evaporation of between 10 and 11 pounds per square foot of heating surface per hour.

Fig. 109 shows the relation between steam consumption per indicated horse power hour and cut-off at the several nominal speeds. Similarly, Fig. 110 shows the relation between indicated horse power and cut-off at the several speeds. In each diagram the curves have been extended somewhat beyond the experimental points, but the error introduced thereby should not alter much the final results. It is now only necessary to select for each speed the cut-off at which the product of indicated horse power, as shown by Fig. 110, and steam consumption, as shown by Fig. 109, is between 25,000 and 26,000 pounds (the maximum capacity of the boiler). These critical cut-offs are indicated on the diagrams Figs. 109 and 110, with a cross mark, the values of the several factors being shown in the following table:

Nominal Speed in R. P. M.	Cut-off in Per Cent.	Steam per Indicated Horse Power Hour.	Maximum Cylinder Horse Power.
40	69	36.2	715
80	44.5	25.1	1010
120	39.5	23.7	1120
160	36.5	23.2	1100

The cylinder horse power given in the last column of the above table is what would be expected by indicator if tests had been run under the conditions of maximum power at the several speeds and cut-offs. It is now only necessary to reduce the cylinder horse power to equivalent draw-bar pull by means of the following equation, in which S. is the speed in miles per hour and F is the corresponding average frictional draw-bar pull (see Table 112):

$$\text{Draw barpull} = \frac{\text{Horse power} \times 375}{S} - F$$

The draw-bar pull at the several speeds, as determined from the above equation is given in the following table:

Speeds in R. P. M.	Maximum Estimated Draw-Bar Pull, Pounds.
40	35706
80	24903
120	17554
160	12346

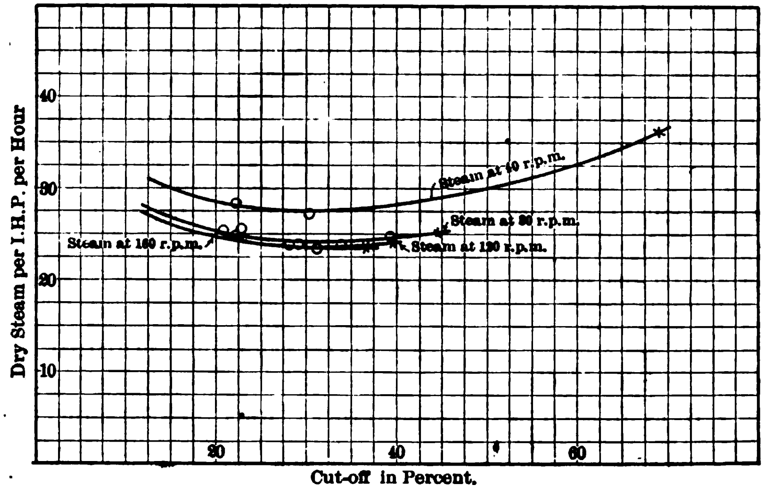


Fig. 109.—Steam Consumption.

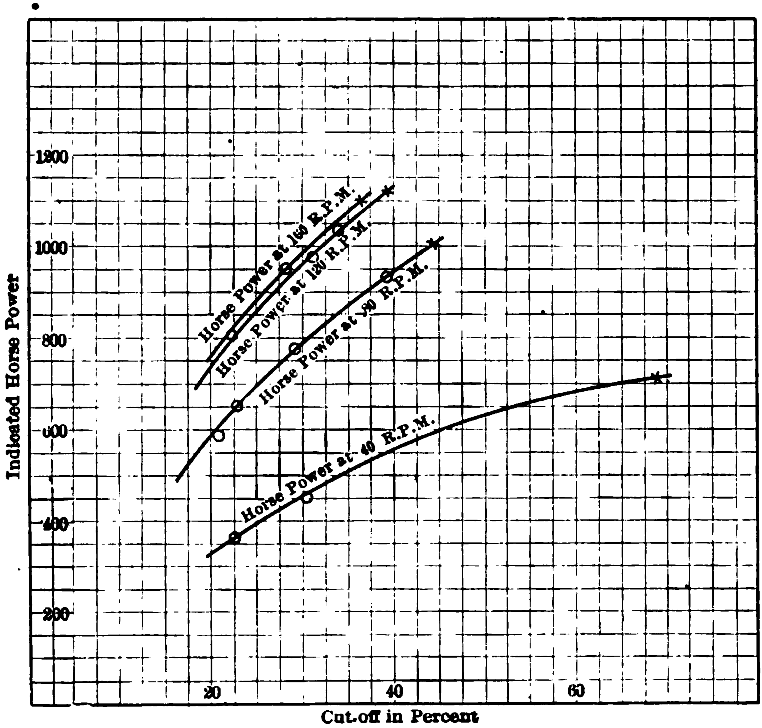


Fig. 110.—Indicated Horse Power.

The full line in the diagram, Fig. 111, shows graphically the results given in the above table. The lowest speed at which the full power of the boiler can be utilized is 30 revolutions per

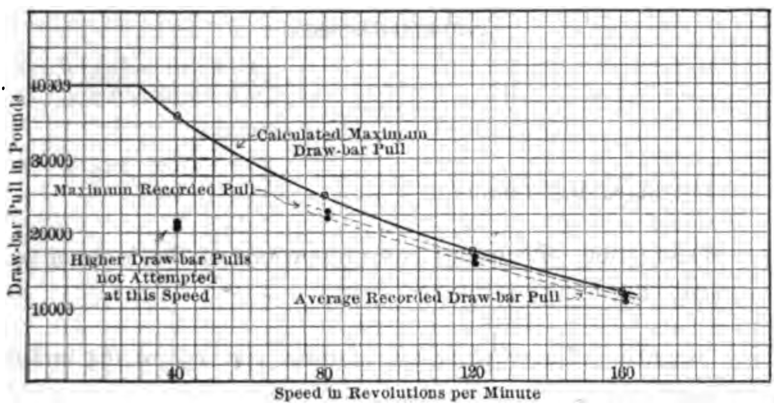


Fig. 111.—Maximum Drawbar Pull.

minute, this speed being determined by the intersection of the straight line of maximum tractive effort with the maximum power curve. The dotted lines on the diagram show the maximum and average draw-bar pulls respectively, at the several speeds as actually recorded in the tests.

APPENDIX 100.

The appendix contains:

1. Description, dimensions and proportions of the locomotive. (pp. 149 to 154 inclusive.)

2. Summary of average results of tests. (pp. 155 to 165 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 166 to 174 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 175 to 189 inclusive.)

5. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 190 to 192 inclusive.)

6. A typical dynamometer diagram for each nominal speed. (pp. 193 and 194).

7. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of Pennsylvania H 6 a Consolidation (2-8-0) Type Locomotive No. 1499.

Built at the Juniata Shops of the Pennsylvania Railroad, Altoona, Pa., March, 1904.

	DRIVING WHEELS.	
1	Number of pairs	4
2	Approximate diameter, inches	56
	MEASURED CIRCUMFERENCE, FEET.	
3	Right, No. 1	14.62
4	" " 2	14.62
5	" " 3	14.62
6	" " 4	14.61
7	" " 5	——
8	Left, " 1	14.62
9	" " 2	14.62
10	" " 3	14.62
11	" " 4	14.61
12	" " 5	——
13	Average	14.62
	ENGINE TRUCK WHEELS.	
14	Number	2
15	Diameter, inches	29.78
	TRAILING WHEELS.	
16	Diameter, inches	——
	WHEEL BASE, FEET.	
17	Driving wheel base	16.550
18	Total wheel base	24.770
19	Gauge of wheels, in inches	56.125
	WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.	
20	On truck	21,000
21	" 1st drivers	44,000
22	" 2nd "	43,200
23	" 3rd "	43,500
24	" 4th "	42,500
25	" 5th "	——
26	" trailers	——
27	Total	194,200
28	" on drivers	173,200
	CYLINDERS.	
29	High pressure, number	2
30	Low " "	——
31	Arrangement	Outside

DIAMETER, INCHES.

32	High pressure, right	21.997
33	" " left	21.993
34	Low " right	——
35	" " left	——

STROKE OF PISTON, FEET.

36	High pressure, right	2.332
37	" " left	2.332
38	Low " right	——
39	" " left	——

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P., right, head end	11.83
41	" " crank "	10.80
42	" left, head "	11.31
43	" " crank "	11.25
44	L. P., right, head "	——
45	" " crank "	——
46	" left, head "	——
47	" " crank "	——

RECEIVER, CUBIC FEET.

48	Volume, right side	——
49	" left "	——

STEAM PORTS, INCHES.

(For piston valves the length equals the circumference of inside of bushing minus the sum of the widths of bridges.)

50	H. P. admission, right, head end, length	20.88
51	" " " " " width	1.49
52	" " " crank " length	20.88
53	" " " " " width	1.49
54	" " left, head " length	20.93
55	" " " " " width	1.48
56	" " " crank " length	21.06
57	" " " " " width	1.48
58	L. P. " right, head " length	——
59	" " " " " width	——
60	" " " crank " length	——
61	" " " " " width	——
62	" " left, head " length	——
63	" " " " " width	——
64	" " " crank " length	——
65	" " " " " width	——
66	H. P. exhaust, right, length	20.898
67	" " " width	3.000
68	" " left, length	20.878
69	" " " width	3.000
70	L. P. " right, length	——

71	L. P. exhaust, right, width	——
72	" " left, length	——
73	" " " width	——

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	3.997
75	" " left	3.998
76	Low " right	——
77	" " left	——

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	" " left	——
80	Low " right	——
81	" " left	——

VALVES.

82	Type	"D" Slide
83	Design	Richardson, balanced
84	Per cent. of balanced to total area	left 58.97; right 58.99
85	Type of link motion	Stephenson, open rods

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	6.17
87	" " left	6.25
88	Low " right	——
89	" " left	——

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure, right, head end	1
91	" " " crank "	1
92	" " left, head "	1
93	" " " crank "	1
94	Low " right, head "	——
95	" " " crank "	——
96	" " left, head "	——
97	" " " crank "	——

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	0.154
99	" " " crank " ....negative	0.010
100	" " left, head "	0.135
101	" " " crank "	0.002
102	Low " right, head "	——
103	" " " crank "	——
104	" " left, head "	——
105	" " " crank "	——

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	No. 16 U. S. G. sheet steel
108	Lead, forward motion, head end, inches	.125 neg.
109	" " " crank " "	.125 neg.
110	" back " head " "	.125 neg.
111	" " " crank " "	.125 neg.
112	Left crank leads.	

BOILER.

113	Type	Belpaire, wide fire-box
114	Outside diameter, 1st ring, inches	71

TUBES.

115	Number	373
116	Outside diameter, inches	2
117	Thickness, inches	0.135
118	Length between tube sheets, inches	164.500
119	Total fire area, square feet	6.089
120	Serve tubes, number of ribs	——
121	" " sq. in. of inside surface in one in. of length	——
122		
123		
124	Boiler pressure, pounds per sq. in.	205

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129		
130		
131		

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	116.125
133	Width	66.000
134	Depth, front end	66.000
135	" back "	53.940
136	Volume, cubic feet	222.380
137	Air inlets to ash pan (dampers closed) sq. ft.	.062
138	" " " " " (" open) " "	3.810
139		
140		

FIRE DOORS.

141	Number	1
142	Area, square feet	1.59
143		

GRATES.

144	Style	rocking, finer
145	Total area, square feet	49.21
146	" " dead grates, square feet	0
147	Width of air spaces, inches	.69

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	——
149	" grates	18.050
150	" fire doors	.067
151	Total air inlets, (148), (149) and (150)	18.120
152	Ratio " " (149) to grate area (145)	.367
153	" " " (151) " " " (145)	.368

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	2677.27
155	" " " fire "	2315.86
156	" " firebox, fire side	166.40
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	2482.26
159	Total, based on inside of firebox and outside of tubes	2843.67

BOILER VOLUMES.

(*With water surface at level of second gauge cock.*)

160	Water space, cubic feet	364.73
161	Steam " " "	78.66

EXHAUST NOZZLE.

162	Double or single	single, 5.75 in. diameter
163	Size of right, inches	
164	" " left, "	
165	Area of right, square inches	
166	" " left, " "	
167	Total area, square inches	25.97

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	21
169	L. P. " " " " "	——
170		

RATIOS.

171	Heating surface (158) to grate area (145)......	50.44
172	Fire area through tubes (119) to grate area (145)	0.12
173	Firebox heating surface (156) to grate area (145)	3.38
174	Tube surface (155) to firebox heating surface (156)..	13.91
175	Firebox volume (136) to grate area (145)......	4.52
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(*power developed at one R. P. M. when pull is one pound.*)

179	....	0.000443

CONSTANTS FOR INDICATED HORSE POWER

(*power developed at one R. P. M. and one pound M. E. P.*)

180	High	pressure	cylinder,	right,	head end	....	0.02686
181	"	"	"	"	crank "	....	0.02597
182	"	"	"	left,	head "	....	0.02685
183	"	"	"	"	crank "	....	0.02596
184	Low	"	"	right,	head "	....	——
185	"	"	"	"	crank "	....	——
186	"	"	"	left,	head "	....	——
187	"	"	"	"	crank "	....	——

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head end	....	6.155
189	"	"	"	"	crank "	....	5.952
190	"	"	"	left,	head "	....	6.153
191	"	"	"	"	crank "	....	5.950
192	Low	"	"	right,	head "	....	——
193	"	"	"	"	crank "	....	——
194	"	"	"	left,	head "	....	——
195	"	"	"	"	crank "	....	——

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499.
PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed: Revolutions, Total	Speed: Revolutions, Average Per Minute	Speed: Equivalent, Speed in Miles Per Hour	Speed: Equivalent, Piston Speed in Feet Per Minute	Position of Levers: Reverse, Notches from Front End	Position of Levers: Test marked thus * not plotted	Position of Levers: Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	
		196	197	198	199	200	201	202	203	204	205
110	40-20-F	2.500	6050	40.33	6.70	188.1	18.5		FULL	40	
111	40-30-F	3.000	7276	40.42	6.72	188.5	17.5		"	45	
103	80-20-F	3.000	16694	92.74	15.40	432.6	18.5		"	55	
109	80-20-F	3.330	16318	81.59	13.55	380.5	18.5		"	53	
112	80-30-F	3.000	14352	79.73	13.24	371.8	17.5		"	60	
118	80-37-F	3.000	14524	80.69	13.40	376.3	16.5		"	71	
108	80-40-F	2.830	13545	79.68	13.23	371.6	16.0	*	"	63	
116	120-30-F	3.000	21632	120.12	19.95	560.2	17.5		"	61	
115	120-35-F	3.000	21714	120.63	20.04	562.6	17.0		"	64	
102	160-20-F	3.500	33669	160.33	26.63	747.7	18.5		"	60	
105	160-27-F	3.000	28375	157.64	26.20	735.3	17.5		"	61	
113	160-30-F	1.000	9524	158.73	26.37	740.3	17.5	*	"	61	
106	160-34-F	1.000	9655	160.91	26.73	750.3	17.0	*	"	65	
117	160-35-P	2.167	20882	160.63	26.68	749.2	17.0		3	65	
101	160-40-P	3.000	28890	160.50	26.66	748.5	15.5		2½	54	
104	160-45-P	2.000	19301	160.84	26.72	750.2	15.0	*	2½	47	
114	160-50-P	1.000	9649	160.82	26.71	750.1	14.5	*	3	43	

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of: Smoke Box, By Thermometer	Smoke Box, By Pyrometer	Laboratory, Dry Bulb	Laboratory, Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer				Steam lost from Boiler, etc. Lbs. per hour
		206	207	208	209	210	211	212	213	214	215	216
110	40-20-F	540	561	75.9	68.5	376.0	73.9	1427				383
111	40-30-F	549	581	72.5	68.8	388.6	73.8	1480				422
103	80-20-F	—	562	78.3	68.5	386.3	63.7	1662				447
109	80-20-F	578	565	70.7	68.4	—	67.1	1658				386
112	80-30-F	643	656	74.1	69.4	381.6	74.0	1742				411
118	80-37-F	687	685	82.2	75.1	385.5	74.2	1766				480
108	80-40-F	753	757	78.9	69.7	378.4	73.1	2110				357
116	120-30-F	709	722	73.6	64.5	385.9	73.0	1769				406
115	120-35-F	714	724	78.1	70.0	384.5	73.4	2001				393
102	160-20-F	652	654	71.1	64.2	376.3	67.4	2028				374
105	160-27-F	691	691	70.3	63.6	374.7	70.9	2112				364
113	160-30-F	686	692	77.9	71.7	377.5	73.3	1763				365
106	160-34-F	712	715	70.7	64.4	372.1	68.1	2110				361
117	160-35-P	717	726	78.6	67.9	372.9	73.5	1821				400
101	160-40-P	706	714	73.5	66.7	344.4	72.5	1968				300
104	160-45-P	770	692	77.3	67.4	339.4	71.3	1940				287
114	160-50-P	717	728	73.5	68.9	332.8	73.2	1918				277

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	In Boiler: Maximum	In Boiler: Minimum	In Branch Pipe	Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box: Front of Diaphragm	In Smoke Box: Back of Diaphragm	In Fire Box	In Ash-Pan	Injectors: Hours in Action: Total, Right	Total, Left
		217	218	219	220	221	222	223	224	225	226	227
110	40-20-F	200.4	203.5	196.5	——	14.60	——	1.05	.70	.56	1.45	0
111	40-30-F	203.4	205.5	200.0	202.4	14.46	——	1.36	.95	.51	2.04	0
103	80-20-F	197.6	202.0	193.5	197.3	14.41	2.06	1.63	1.37	1.03	2.71	0
109	80-20-F	191.6	196.1	186.6	——	14.67	——	1.70	.68	.59	2.97	0
112	80-30-F	200.7	202.5	195.0	199.6	14.45	2.50	2.46	1.91	1.03	2.96	0
118	80-37-F	201.4	205.0	191.0	194.6	14.51	3.60	3.10	1.28	1.13	3.00	0
108	80-40-F	183.8	199.0	148.0	161.0	14.46	4.86	4.17	1.62	1.09	2.83	0
116	120-30-F	198.7	206.0	182.5	195.7	14.59	3.70	3.28	2.04	1.00	3.00	0
115	120-35-F	193.1	205.0	179.0	188.2	14.44	4.66	3.61	2.42	1.69	3.00	.003
102	160-20-F	189.3	194.5	173.5	187.4	14.49	2.94	2.74	1.71	1.03	3.45	0
105	160-27-F	181.6	194.0	170.5	169.4	14.55	3.59	3.38	1.86	1.03	3.00	0
113	160-30-F	176.4	184.0	166.5	175.7	14.48	3.70	3.57	2.06	1.07	1.00	0
106	160-34-F	185.9	196.0	180.0	168.7	14.58	3.91	4.08	2.00	1.08	1.00	0
117	160-35-P	201.8	206.0	195.0	165.4	14.48	4.25	3.62	2.17	1.09	2.17	.019
101	160-40-P	176.9	192.0	166.0	110.9	14.50	4.31	3.76	1.15	.91	3.00	.016
104	160-45-P	172.1	185.0	157.0	108.0	14.47	4.07	3.92	1.93	1.15	2.00	0
114	160-50-P	172.9	195.0	160.0	94.0	14.45	3.57	3.38	2.10	1.15	1.00	0

Test Number	Laboratory Designation	Quality of steam: In Dome	In Branch Pipe	Degrees of Superheat in Branch Pipe	Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Kind	Coal Fired: Total	Coal Fired: Per Cent of Moisture	Total: Dry Coal Fired	Total: Combustible by Analysis	Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
110	40-20-F	.9884	.9964	0	.9916	Bituminous	2817	.95	2790	2590	200
111	40-30-F	.9903	.9918	0	.9929	"	4148	1.05	4104	3808	296
103	80-20-F	.9889	.9927	0	.9900	"	6369	1.58	6268	5818	450
109	80-20-F	.9882	——	—	.9915	"	7039	.84	6980	6186	794
112	80-30-F	.9886	.9924	0	.9917	"	8393	1.10	8301	7779	522
113	80-37-F	.9883	.9953	0	.9915	"	10466	1.17	10344	9576	768
108	80-40-F	.9897	1.0006	.461	.9925	"	11264	.90	11163	10107	1056
116	120-30-F	.9882	.9913	0	.9915	"	10644	.90	10547	9340	1207
115	120-35-F	.9885	.9917	0	.9917	"	12249	1.05	12122	11233	889
102	160-20-F	.9887	.9972	0	.9918	"	11546	.84	11450	10148	1303
105	160-27-F	.9894	.9977	0	.9923	"	11580	.81	11486	10701	785
113	160-30-F	.9900	.9940	0	.9927	"	4048	1.15	4001	3726	276
106	160-34-F	.9850	.9895	0	.9891	"	4672	.95	4627	4310	317
117	160-35-P	.9877	.9858	0	.9911	"	9098	.85	9021	8326	695
101	160-40-P	.9899	1.0109	19.74	.9902	"	12878	.95	12755	11901	855
104	160-45-P	.9907	1.0150	27.26	.9932	"	7841	.98	7764	7211	553
114	160-50-P	.9901	.9838	0	.9928	"	3769	1.22	3723	3497	226

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs. Total: Cinders Collected in Smoke Box	Sparks Discharged From Stack	Cinders and Sparks	Analysis of Coal, Per Cent: Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
110	40-20-F	185	85	270	75.57	16.88	.95	7.10	.86		
111	40-30-F	183	72	255	75.88	16.44	1.05	7.18	.82		
103	80-20-F	120	115	235	75.12	16.23	1.58	7.07	.80		
109	80-20-F	388	99	487	71.86	16.02	.84	11.28	.77		
112	80-30-F	612	119	731	76.68	16.00	1.10	6.22	.78		
113	80-37-F	765	192	957	75.16	16.33	1.17	7.34	.85		
108	80-40-F	1215	590	1805	73.61	16.12	.90	9.37	.84		
116	120-30-F	1221	315	1536	71.55	16.20	.90	11.35	1.00		
115	120-35-F	1447	382	1829	75.45	16.25	1.05	7.25	1.71		
102	160-20-F	973	286	1259	71.86	16.02	.84	11.28	.77		
105	160-27-F	1088	468	1556	76.07	16.34	.81	6.78	.81		
118	160-30-F	50	91	141	75.75	16.29	1.15	6.81	1.10		
106	160-34-F	—	—	—	75.97	16.28	.95	6.80	.60		
117	160-35-P	835	232	1067	75.10	16.42	.85	7.63	.85		
101	160-40-P	1272	681	1953	76.15	16.26	.95	6.64	.72		
104	160-45-P	1278	254	1532	75.79	16.17	.98	7.06	.74		
114	160-50-P	245	56	301	76.38	16.40	1.22	6.00	1.08		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B. T. U.: Of Dry Coal	Of Combustible	Of Cinders	Of Sparks		Analysis of Smoke Box Gases, Per Cent: Oxygen O	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
110	40-20-F	14109	15199	11004	7483		7.40	.07	11.70	80.83		
111	40-30-F	14013	15100	8363	7263		5.96	.07	12.90	81.07		
103	80-20-F	14144	15239	—	—		5.38	1.40	12.15	81.07		
109	80-20-F	13482	15151	—	—		6.00	1.08	11.97	80.95		
112	80-30-F	14242	15198	10564	7923		3.33	2.57	12.40	81.70		
113	80-37-F	14009	15997	11005	9024		3.60	4.13	11.70	80.57		
108	80-40-F	13769	15207	10564	8804		2.06	6.54	11.02	80.38		
116	120-30-F	13769	15550	10684	8033		3.67	3.30	12.23	80.80		
115	120-35-F	14134	15241	10784	7923		2.20	4.53	12.43	80.84		
102	160-20-F	13482	15151	11158	8772		4.44	1.13	13.03	81.40		
105	160-27-F	14755	15805	10454	8584		5.07	1.63	11.73	81.57		
113	160-30-F	14249	15315	12325	10234		3.05	2.70	12.55	81.70		
106	160-34-F	14612	15689	—	—		5.30	1.50	11.40	81.80		
117	160-35-P	14651	15871	11224	9024		6.90	2.25	9.75	81.10		
101	160-40-P	14119	15124	9464	7813		3.17	2.93	11.67	82.23		
104	160-45-P	14602	15078	9024	7043		3.00	3.43	12.60	80.97		
114	160-50-P	14705	15654	13205	10124		3.60	3.40	12.00	81.00		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Water, in Pounds: Delivered to Injectors	Water, Lost: From Boiler	Water, Lost: From	Water, Lost: From	Water, Lost: Total	Water: Delivered to Boiler and Presumably Evaporated	Dynamometer, Drawbar Pull in Pounds: Average	Dynamometer, Drawbar Pull in Pounds: Maximum	Dynamometer, Drawbar Pull in Pounds: Minimum
		259	260	261	262	263	264	265	266	267
110	40-20-F	27071	0			0	27071	15706	16208	15204
111	40-30-F	38744	0			0	38744	20864	21468	20330
103	80-20-F	51586	0			0	51586	12587	13250	10825
109	80-20-F	51219	0			0	51219	13314	13850	12500
112	80-30-F	57620	0			0	57620	17831	18251	17300
118	80-37-F	70969	0			0	70969	22078	23110	20754
108	80-40-F	64111	0			0	64111	20779	23054	15769
116	120-30-F	70355	0			0	70355	14813	15977	12650
115	120-35-F	75575	0			0	75575	15888	16900	15104
102	160-20-F	71546	0			0	71546	8666	9456	7704
105	160-27-F	69344	0			0	69344	9929	10720	8729
113	160-30-F	23935	0			0	23935	10835	11523	9878
106	160-34-F	26007	0			0	26007	10868	11528	10103
117	160-35-P	56115	0			0	56115	10902	11258	10500
101	160-40-P	71355	0			0	71355	9118	9954	7804
104	160-45-P	47782	0			0	47782	8366	9302	7605
114	160-50-P	24069	0			0	24069	*7182	*Estimated	

Test Number	Laboratory Designation	Cut-off, Per Cent. of Stroke: High Pressure Cylinder, Right Side, Head End	H.P. Right Side, Crank End	H.P. Left Side, Head End	H.P. Left Side, Crank End	Low Pressure Cylinder, Right Side, Head End	L.P. Right Side, Crank End	L.P. Left Side, Head End	L.P. Left Side, Crank End	Release, Per Cent. of Stroke: High Pressure Cylinder, Right Side, Head End	H.P. Right Side, Crank End	H.P. Left Side, Head End	H.P. Left Side, Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
110	40-20-F	23.22	20.75	25.10	20.68					72.84	66.66	74.14	67.11
111	40-30-F	32.00	27.63	33.55	28.63					77.42	70.61	78.32	72.62
103	80-20-F	23.80	21.00	23.80	22.60					72.10	65.50	73.70	67.90
109	80-20-F	21.04	19.50	22.78	20.20					68.86	63.80	71.65	65.60
112	80-30-F	29.63	27.16	31.84	28.34					76.53	69.85	78.11	72.03
118	80-37-F	38.89	37.66	40.72	40.08					80.69	76.95	81.95	77.95
108	80-40-F	41.61	40.17	43.22	40.75					82.39	78.00	84.34	78.14
116	120-30-F	30.81	30.02	32.84	31.63					75.03	70.55	77.21	72.08
115	120-35-F	34.66	32.44	35.64	33.08					77.80	72.62	79.33	73.97
102	160-20-F	22.80	21.06	23.15	22.12					67.87	61.26	66.74	62.32
105	160-27-F	28.13	27.68	28.08	28.21					71.61	68.50	72.87	67.80
113	160-30-F	30.92	28.21	31.57	29.79					72.50	66.43	73.96	67.36
106	160-34-F	32.10	32.60	34.16	32.80					71.36	68.46	72.28	68.32
117	160-35-P	36.21	34.07	36.79	34.14					75.61	72.75	78.18	72.32
101	160-40-P	42.03	41.55	44.32	40.66					81.42	78.80	82.06	78.77
104	160-45-P	45.60	45.03	45.80	43.92					84.12	80.70	84.30	80.80
114	160-50-P	50.50	47.64	51.20	49.86					83.70	80.28	84.70	82.00

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
110	40-20-F					87.5	30.5	88.7	80.5				
111	40-80-F					85.8	28.3	84.2	27.8				
103	80-20-F					48.1	34.8	41.2	34.5				
109	80-20-F					42.6	36.2	48.7	85.8				
112	80-80-F					36.7	29.8	36.3	28.8				
118	80-87-F					30.6	24.8	32.8	23.8				
108	80-40-F					28.5	21.9	29.1	18.4				
116	120-80-F					36.1	29.8	36.7	29.0				
115	120-85-F					34.1	29.0	34.2	28.5				
102	160-20-F					46.2	38.1	45.7	88.1				
105	160-27-F					40.8	32.4	40.0	82.0				
113	160-80-F					88.4	31.9	89.6	83.0				
106	160-84-F					36.9	30.4	88.8	29.5				
117	160-85-P					37.6	30.7	88.5	80.1				
101	160-40-P					28.5	22.7	29.7	21.5				
104	160-45-P					27.7	21.0	28.1	21.2				
114	160-50-P					24.7	22.1	27.1	22.6				

Test Number	Laboratory Designation	Pressure from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
110	40-20-F	198.4	195.8	198.9	188.6					1.1985
111	40-80-F	201.8	199.0	202.1	196.8					1.1988
103	80-20-F	180.8	166.8	166.6	155.6					1.2090
109	80-20-F	175.8	178.8	178.3	164.8					1.2045
112	80-80-F	198.1	186.7	198.9	178.1					1.1983
118	80-87-F	194.2	188.2	194.2	169.8					1.1982
108	80-40-F	178.1	172.2	174.5	161.7					1.1974
116	120-80-F	189.6	169.8	192.1	156.8					1.1981
115	120-85-F	178.2	164.8	177.4	157.2					1.1968
102	160-20-F	175.6	154.5	168.2	136.0					1.2040
105	160-27-F	163.7	146.6	159.2	132.1					1.1996
113	160-80-F	162.0	144.0	160.1	136.0					1.1966
106	160-84-F	156.4	189.8	151.8	130.5					1.2080
117	160-85-P	151.6	133.0	151.4	130.6					1.1980
101	160-40-P	102.7	100.1	104.4	98.7					1.1975
104	160-45-P	90.9	87.8	92.4	86.2					1.1980
114	160-50-P	77.1	74.1	77.4	73.9					1.1963

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Pressures from Indicator Cards: Steam Chest Pressures, Pounds Per Square Inch: High Pressure: Right Side	High Pressure: Left Side	Low Pressure: Right Side	Low Pressure: Left Side		Pressures at Cut-off, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		301	302	303	304	305	306	307	308	309
110	40-20-F	202.0	202.8				169.5	168.1	170.6	166.7
111	40-30-F	203.3	203.8				167.0	168.6	169.9	165.1
103	80-20-F	194.1	188.0				131.8	133.6	135.0	125.0
109	80-20-F	183.1	193.0				139.7	142.5	138.3	134.5
112	80-30-F	201.3	200.8				154.0	145.6	152.5	141.1
118	80-37-F	200.3	198.7				151.6	145.2	152.0	137.2
108	80-40-F	180.2	178.4				140.0	136.4	142.1	143.3
116	120-30-F	196.6	195.9				131.9	113.2	131.4	111.0
115	120-35-F	186.6	187.8				126.5	116.9	131.4	118.0
102	160-20-F	188.2	183.2				117.8	108.2	113.3	96.3
105	160-27-F	179.9	176.1				112.5	105.0	109.9	97.9
113	160-30-F	176.0	177.8				108.5	99.4	105.7	92.3
106	160-34-F	174.5	172.1				111.0	97.6	98.1	91.8
117	160-35-P	165.6	163.9				100.4	89.5	100.4	90.5
101	160-40-P	114.7	118.4				70.5	70.9	70.7	72.3
104	160-45-P	102.4	103.8				63.8	64.3	67.0	64.7
114	160-50-P	87.8	78.3				52.4	54.3	53.7	52.8

Test Number	Laboratory Designation	Pressures from Indicator Cards: Pressures at Cut-off, Pounds Per Square Inch: Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Pressures at Release, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
110	40-20-F					53.5	53.1	54.6	53.1				
111	40-30-F					66.1	64.4	68.4	63.5				
103	80-20-F					40.8	44.1	40.2	40.7				
109	80-20-F					44.3	44.8	44.8	43.5				
112	80-30-F					60.2	56.3	60.3	52.8				
118	80-37-F					71.9	58.9	72.3	67.8				
108	80-40-F					69.8	66.9	68.7	66.2				
116	120-30-F					53.1	46.7	53.6	47.0				
115	120-35-F					53.8	49.9	56.3	51.8				
102	160-20-F					39.6	37.1	38.3	35.2				
105	160-27-F					44.5	41.2	40.7	40.1				
113	160-30-F					43.6	41.3	42.7	41.1				
106	160-34-F					50.8	43.6	44.9	43.8				
117	160-35-P					42.8	38.4	44.9	40.1				
101	160-40-P					32.3	33.3	34.4	34.4				
104	160-45-P					30.1	32.0	32.9	32.0				
114	160-50-P					27.7	28.9	28.4	28.9				

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Beginning of Compression, Pounds Per Square Inch								Least Back Pressure, Pounds Per Square Inch			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
110	40-20-F	3.5	4.1	4.2	4.6					0.0	0.5	1.2	2.2
111	40-30-F	2.3	2.4	2.9	2.2					0.0	0.0	1.3	.8
103	80-20-F	5.6	4.7	5.0	7.2					2.6	1.9	2.3	4.5
109	80-20-F	3.8	5.9	5.2	4.8					1.9	1.6	2.0	1.2
112	80-30-F	4.6	5.8	5.5	4.1					1.7	1.4	1.5	1.8
118	80-37-F	5.5	4.8	5.2	4.9					2.9	1.2	2.2	2.1
108	80-40-F	7.5	6.4	5.1	3.5					4.5	6.4	1.7	1.6
116	120-30-F	8.8	8.8	9.1	8.3					3.9	2.0	4.1	2.8
115	120-35-F	8.8	8.8	9.4	8.4					4.7	2.2	5.5	3.1
102	160-20-F	9.6	9.2	7.1	6.5					5.9	4.3	2.8	1.9
105	160-27-F	12.3	10.7	8.3	8.5					7.2	4.6	3.3	4.5
113	160-30-F	10.6	10.0	9.8	9.4					4.7	4.1	3.9	4.4
106	160-34-F	15.1	10.9	8.5	10.7					10.0	4.7	5.4	5.5
117	160-35-P	10.5	9.2	10.6	9.8					6.1	3.1	6.3	4.1
101	160-40-P	9.3	10.9	10.3	10.6					3.8	3.7	4.8	5.0
104	160-45-P	9.5	9.7	10.5	9.3					3.8	3.5	5.2	4.0
114	160-50-P	10.4	9.6	9.7	10.3					5.6	4.4	5.0	5.0

Test Number	Laboratory Designation	Pressures from Indicator Cards				Boiler					
		Least Back Pressure, Pounds Per Square Inch				Dry Coal Fired Pounds		Evaporation, Pounds			
		Low Pressure Cylinder						Steam Per Hour			
		Right Side		Left Side							
		Head End	Crank End	Head End	Crank End	Per Hour	Per Hour Per Square Foot of Grate Surface	Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
110	40-20-F					1116	22.68	10828	10737	4.33	9.622
111	40-30-F					1368	27.80	12915	12823	5.17	9.373
103	80-20-F					2089	42.40	17195	17022	6.86	8.148
109	80-20-F					2094	42.55	15381	15255	6.15	7.286
112	80-30-F					2767	56.22	19207	19048	7.67	6.885
118	80-37-F					3448	70.07	23656	23454	9.45	6.802
108	80-40-F					3940	80.06	22630	22460	9.05	5.701
116	120-30-F					3516	71.45	23452	23252	9.37	6.613
115	120-35-F					4041	82.11	25192	24982	10.06	6.183
102	160-20-F					3271	66.50	20442	20275	8.17	6.198
105	160-27-F					3829	77.80	23114	22934	9.24	5.990
113	160-30-F					4001	81.31	23934	23755	9.57	5.937
106	160-34-F					4627	94.04	26007	25722	10.36	5.558
117	160-35-P					4163	84.59	25896	25665	10.34	6.166
101	160-40-P					4252	86.40	23785	23550	9.49	5.539
104	160-45-P					3882	78.90	23891	23726	9.56	6.112
114	160-50-P					3723	75.66	24069	23894	9.63	6.418

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499, PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Boiler: Equiv't Evap'n: Per Hour, Per Sq. Ft. of Heat. Surface	Boiler: Equiv't Evap'n: Per Pound of Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Dry Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch, High Pressure Cylinder: Right Side Head End	Right Side Crank End	Left Side Head End	Left Side Crank End
		344	345	346	347	348	349	350	351	352	353	354
110	40-20-F	12870	5.18	11.42	11.53	12.42	373.00	78.98	87.66	81.61	92.35	81.43
111	40-30-F	15372	6.19	11.12	11.24	12.11	445.50	77.45	109.72	100.21	114.57	100.86
103	80-20-F	20581	8.29	9.69	9.85	10.61	596.50	57.25	66.76	64.84	70.55	63.16
109	80-20-F	18375	7.40	8.70	8.78	9.90	532.60	59.92	72.57	65.27	70.16	64.46
112	80-30-F	22825	9.20	8.16	8.25	8.80	661.60	55.94	97.20	86.02	99.71	86.76
118	80-37-F	28102	11.32	8.06	8.15	8.80	814.60	53.15	112.12	106.32	115.90	101.61
108	80-40-F	26895	10.83	6.76	6.83	7.54	779.60	47.88	107.53	101.66	112·75	103.25
116	120-30-F	27856	11.22	7.85	7.92	8.95	807.40	55.57	81.29	71.05	83.74	70.93
115	120-35-F	29900	12.04	7.32	7.40	7.99	866.70	50.59	84.29	75.30	88.31	76.98
102	160-20-F	24410	9.83	7.40	7.46	8.42	707.52	48.40	50.98	44.26	52.18	42.03
105	160-27-F	27513	11.08	7.13	7.19	7.71	797.50	47.04	58.29	56.88	59.96	53.76
118	160-30-F	28427	11.45	7.02	7.11	7.63	824.00	48.19	61.67	54.26	62.81	52.60
106	160-34-F	30943	12.47	6.62	6.69	7.18	896.90	45.47	63.44	60.02	65.09	58.44
117	160-35-P	30747	12.39	7.34	7.39	8.00	891.30	48.69	62.77	56.83	64.68	56.80
101	160-40-P	28203	11.36	6.57	6.63	7.11	817.50	45.37	49.46	50.18	51.10	50.18
104	160-45-P	28424	11.45	7.25	7.32	7.88	823.90	50.51	45.82	48.07	48.06	47.13
114	160-50-P	28583	11.51	7.58	7.68	8.17	828.40	50.42	39.51	39.69	41.15	40.24

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square inch, Low Pressure Cylinder: Right Side Head End	Right Side Crank End	Left Side Head End	Left Side Crank End	Receiver Pressure: Right Side	Receiver Pressure: Left Side	Number of Expansions: Right Side Head End	Right Side Crank End	Left Side Head End	Left Side Crank End
		355	356	357	358	359	360	361	362	363	364
110	40-20-F							2.416	2.455	2.346	2.454
111	40-30-F							2.036	2.118	1.998	2.103
103	80-20-F							2.355	2.399	2.421	2.604
109	80-20-F							2.455	2.462	2.434	2.444
112	80-30-F							2.131	2.125	2.072	2.103
118	80-37-F							1.824	1.811	1.793	1.738
108	80-40-F							1.763	1.740	1.754	1.719
116	120-30-F							2.037	1.993	2.005	1.943
115	120-35-F							1.928	1.930	1.930	1.922
102	160-20-F							2.335	2.262	2.265	2.205
105	160-27-F							2.088	2.061	2.124	2.003
113	160-30-F							1.973	1.980	1.988	1.916
106	160-34-F							1.894	1.826	1.838	1.806
117	160-35-P							1.820	1.862	1.860	1.841
101	160-40-P							1.730	1.710	1.680	1.550
104	160-45-P							1.671	1.639	1.674	1.668
114	160-50-P							1.533	1.559	1.536	1.526

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
110	40-20-F	95.0	85.5	100.0	85.3					180.4	185.3		
111	40-30-F	119.1	105.2	124.4	105.8					224.3	230.2		
103	80-20-F	166.3	156.1	175.7	152.0					322.3	327.6		
109	80-20-F	159.0	138.3	153.8	136.5					297.3	290.3		
112	80-30-F	208.1	178.1	213.5	179.6					386.2	393.0		
118	80-37-F	243.0	223.6	251.0	212.8					466.6	463.9		
108	80-40-F	230.1	210.3	241.2	213.6					440.5	454.8		
116	120-30-F	262.3	221.7	270.1	221.2					483.9	491.2		
115	120-35-F	173.1	235.9	286.0	241.1					509.0	527.1		
102	160-20-F	219.5	184.3	224.7	174.9					403.8	399.5		
105	160-27-F	246.8	230.8	253.8	220.0					477.6	473.8		
113	160-30-F	262.9	223.6	265.0	216.7					486.5	481.7		
106	160-34-F	274.2	250.8	281.2	244.1					525.0	525.3		
117	160-35-P	270.8	237.1	279.0	236.8					507.9	515.8		
101	160-40-P	213.2	209.2	220.2	209.1					422.4	429.3		
104	160-45-P	197.9	200.8	207.6	196.8					398.7	404.3		
114	160-50-P	170.7	165.8	177.7	168.0					336.4	345.7		

Test Number	Laboratory Designation	Engines						Locomotive			
		Division of Power			Consumed per I. H. P., Hour			Dynamometer Horse Power	Pounds per D. H. P., Hour		B. T. U. per D. H. P., Hour
		Total		Total I. H. P.							
		Right Side	Left Side		Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.		Of Dry Coal	Of Dry Steam	
		377	378	379	380	381	382	383	384	385	386
110	40-20-F	180.4	185.3	365.7	2.94	28.33	41582	280.6	3.84	36.91	54120
111	40-30-F	224.3	230.2	454.5	2.91	27.29	40806	373.5	3.54	33.21	49650
103	80-20-F	322.3	327.6	650.0	3.13	25.51	44265	517.0	3.94	32.07	55657
109	80-20-F	297.3	290.3	587.6	3.47	25.31	46834	481.2	4.24	30.88	57198
112	80-30-F	386.2	393.0	779.3	3.48	23.92	49482	629.8	4.30	29.59	61230
118	80-37-F	466.6	463.9	930.5	3.63	24.70	53766	789.2	4.28	29.12	63387
108	80-40-F	440.5	454.8	895.2	4.33	24.69	59645	733.4	5.29	30.14	72810
116	120-30-F	483.9	491.2	975.1	3 54	23.43	48783	783.1	4.38	28.99	60851
115	120-35-F	509.0	527.1	1036.1	3.84	23.74	54215	848.6	4.69	28.98	66205
102	160-20-F	403.8	399.5	803.3	4.00	24.78	53885	615.5	5.22	32.34	70830
105	160-27-F	477.6	473.8	951.4	3.96	23.73	58449	693.5	5.43	32.55	80178
113	160-30-F	486.5	481.7	968.2	4.07	24.17	57978	762.0	5.17	30.71	73661
106	160-34-F	525.0	525.3	1050.3	4.34	24.15	63470	774.2	5.89	32.76	86121
117	160-35-P	507.9	515.8	1023.7	4.00	24.69	58640	775.7	5.28	32.58	77401
101	160-40-P	422.4	429.3	851.7	4.98	27.80	69597	648.3	6.48	35.87	91443
104	160-45-P	398.7	404.3	803.1	4.77	29.19	66809	596.0	6.44	39.33	90100
114	160-50-P	336.4	345.7	682.1	5.40	34.62	79384	511.7	7.19	46.16	105730

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	I. H. P. Per Square Foot of: Heating Surface	Grate Surface	D. H. P. Per Square Foot of: Heating Surface	Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
110	40-20-F	1.94	18.64	27332	.1473	7.43	.1130	5.70	20463	85.1	19.97	4764
111	40-30-F	1.79	16.77	25073	.1831	9.24	.1505	7.59	25380	81.0	18.97	4524
103	80-20-F	1.99	16.19	28096	.2618	13.21	.2083	10.50	15817	133.0	13.57	3237
109	80-20-F	2.14	15.58	28846	.2367	11.94	.1938	9.78	16256	106.4	12.35	2944
112	80-30-F	2.17	14.94	30921	.3139	15.84	.2537	12.80	22060	149.5	17.74	4233
118	80-37-F	2.17	14.70	32007	.3748	18.91	.3179	16.04	26005	141.3	16.57	3953
108	80-40-F	2.67	15.22	36761	.3607	18.19	.2954	14.99	25361	161.8	19.23	4584
116	120-30-F	2.21	14.65	30491	.3928	19.81	.3175	16.02	18320	187.0	14.74	3513
115	120-35-F	2.37	14.64	33441	.4174	21.05	.3418	17.24	19386	187.5	14.70	3509
102	160-20-F	2.64	16.33	35520	.3236	16.32	.2479	12.51	11318	187.8	11.09	2644
105	160-27-F	2.75	16.44	40501	.3833	19.33	.2794	14.09	18622	257.9	15.48	3693
113	160-30-F	2.61	15.50	37200	.3900	19.67	.3070	15.48	18768	206.2	12.29	2932
106	160-34-F	3.00	16.55	43739	.4231	21.34	.3119	15.73	14782	276.1	16.24	3873
117	160-35-P	2.67	16.45	39091	.4123	20.80	.3125	15.76	14388	248.0	14.61	3485
101	160-40-P	3.27	18.11	46142	.3431	17.31	.2611	13.17	11978	203.4	11.99	2860
104	160-45-P	3.25	19.86	45510	.3235	16.32	.2401	12.11	11268	207.1	12.18	2806
114	160-50-P	3.63	23.32	53406	.2748	13.86	.2061	10.40	9573	170.4	10.03	2392

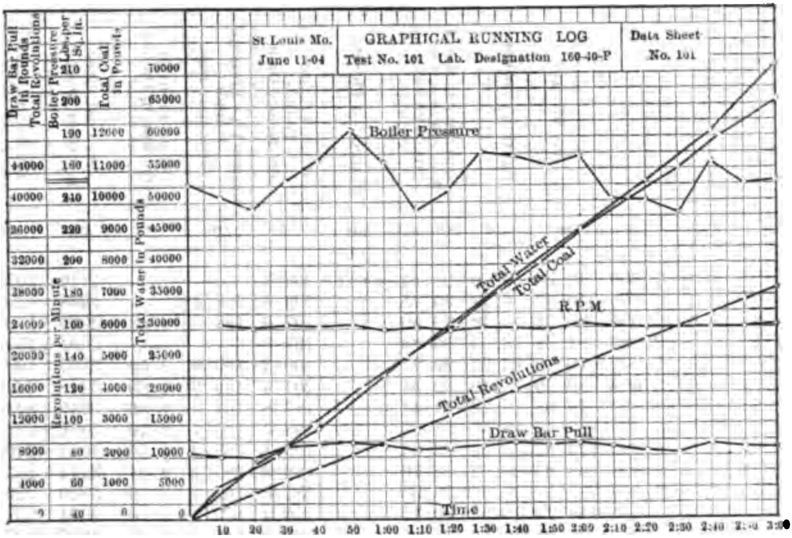
Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
110	40-20-F	76.74	4.71	512.2	6.55	556	379.2				6-16-04
111	40-30-F	82.18	5.13	406.3	5.19	740	478.0				6-18-04
103	80-20-F	79.54	4.57	288.9	3.69	1024	672.2				5-25-04
109	80-20-F	81.90	4.45	319.3	4.08	954	608.3				6- 4-04
112	80-30-F	80.82	4.16	246.8	3.16	1247	786.7				6-20-04
118	80-37-F	84.82	4.01	204.5	2.61	1563	949.5				6-24-04
108	80-40-F	81.92	3.50	197.7	2.53	1453	982.4				6-15-04
116	120-30-F	80.82	3.21	194.9	2.49	1560	996.6				6-22-04
115	120-35-F	81.91	3.34	178.4	2.28	1680	1088.5				6-21-04
102	160-20-F	76.62	3.62	232.1	2.97	1219	836.2				6- 7-04
105	160-27-F	72.89	3.17	184.5	2.36	1373	1052.8				6- 9-04
113	160-30-F	78.70	3.45	189.9	2.43	1509	1022.8				6-20-04
106	160-34-F	73.71	2.95	177.1	2.26	1533	1096.2				6- 8-04
117	160-35-P	75.78	3.29	189.4	2.42	1536	1025.4				6-22-04
101	160-40-P	76.12	2.77	210.1	2.69	1384	924.4				6-11-04
104	160-45-P	74.22	2.83	237.4	3.04	1180	818.0				6-10-04
114	160-50-P	75.02	2.41	260.9	3.34	1013	744.4				6-21-04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 1499.

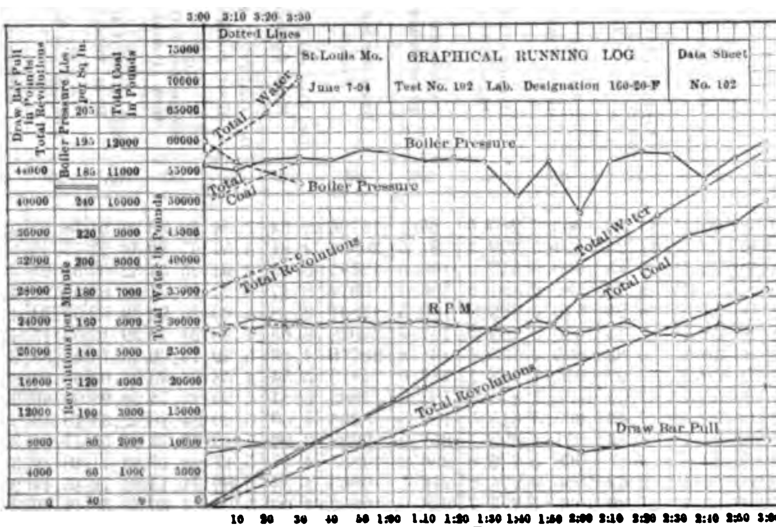
Pennsylvania Railroad Company.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft Front of Diaphragm Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	206	217	220	222	338	341
110	40-20-F	2.500	40.83	6.70	22.44	Full	200.4	——	——	1116	10737
111	40-30-F	3.000	40.42	6.72	30.45	"	203.4	202.4	——	1368	12823
103	80-20-F	3.000	92.74	15.40	22.80	"	197.6	197.3	2.08	2089	17022
109	80-20-F	3.330	81.59	13.55	20.88	"	191.6	——	——	2094	15255
112	80-30-F	3.000	79.73	13.24	29.24	"	200.7	199.6	2.50	2767	19048
118	80-37-F	3.000	80.69	13.40	39.34	"	201.4	194.6	3.60	3448	23454
108	80-40-F	2.830	79.68	13.23	41.44	"	183.8	161.0	4.86	3940	22460
116	120-30-F	3.000	120.12	19.95	31.33	"	198.7	195.7	3.70	3516	23252
115	120-35-F	3.000	120.63	20.04	33.96	"	193.1	188.2	4.66	4041	24982
102	160-20-F	3.500	160.33	26.63	22.16	"	189.3	187.4	2.94	3271	20275
105	160-27-F	3.000	157.64	26.20	28.03	"	181.6	169.4	3.59	3829	22934
113	160-30-F	1.000	158.73	26.37	30.12	"	176.4	175.7	3.70	4001	23755
106	160-34-F	1.000	160.91	26.73	32.92	"	185.9	163.7	3.91	4627	25722
117	160-35-P	2.167	160.63	26.68	35.30	3	201.8	165.4	4.25	4163	25665
101	160-40-P	3.000	160.50	26.66	42.14	2½	176.9	110.9	4.21	4252	23550
104	160-45-P	2.000	160.84	26.72	45.09	2½	172.1	108.0	4.07	3882	23726
114	160-50-P	1.000	160.82	26.71	49.80	3	172.9	94.0	3.57	3723	23894

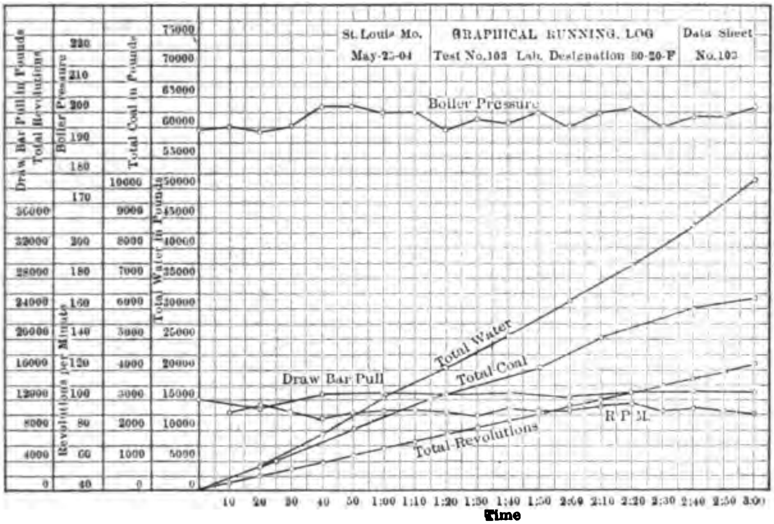
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		347	379	383	395	265	380	384	381	385	350	399
110	40-20-F	11.53	365.7	280.6	85.1	15706	2.94	3.84	28.33	36.91	78.93	4.71
111	40-30-F	11.24	454.5	373.5	81.0	20864	2.91	3.54	27.29	33.21	77.45	5.13
103	80-20-F	9.85	650.0	517.0	133.0	12587	3.13	3.94	25.51	32.07	67.25	4.57
109	80-20-F	8.78	587.6	481.2	106.4	13314	3.47	4.24	25.31	30.88	59.92	4.45
112	80-30-F	8.25	779.3	629.8	149.5	17831	3.48	4.30	23.92	29.59	55.94	4.16
118	80-37-F	8.15	930.5	789.2	141.3	22078	3.63	4.28	24.70	29.12	53.15	4.01
108	80-40-F	6.83	895.2	733.4	161.8	20779	4.33	5.29	24.69	30.14	47.88	3.50
116	120-30-F	7.92	975.1	788.1	187.0	14813	3.54	4.38	23.43	28.99	55.57	3.21
115	120-35-F	7.40	1036.1	848.6	187.5	15883	3.84	4.69	23.74	28.98	50.59	3.84
102	160-20-F	7.46	803.3	615.5	187.8	8666	4.00	5.22	24.78	32.34	48.40	3.62
105	160-27-F	7.19	951.4	693.5	257.9	9929	3.96	5.43	23.73	32.55	47.04	3.17
113	160-30-F	7.11	968.2	762.0	206.2	10835	4.07	5.17	24.17	30.71	48.19	3.45
106	160-34-F	6.69	1050.3	774.2	276.1	10863	4.34	5.89	24.15	32.76	45.47	2.95
117	160-35-P	7.39	1023.7	775.7	248.0	10902	4.00	5.28	24.69	32.58	48.69	3.29
101	160-40-P	6.63	851.7	648.3	203.4	9118	4.93	6.48	27.30	35.87	45.37	2.77
104	160-45-P	7.32	803.1	596.0	207.1	8366	4.77	6.44	29.19	39.33	50.51	2.82
114	160-50-P	7.68	682.1	511.7	170.4	7182	5.40	7.19	34.62	46.16	50.42	2.41



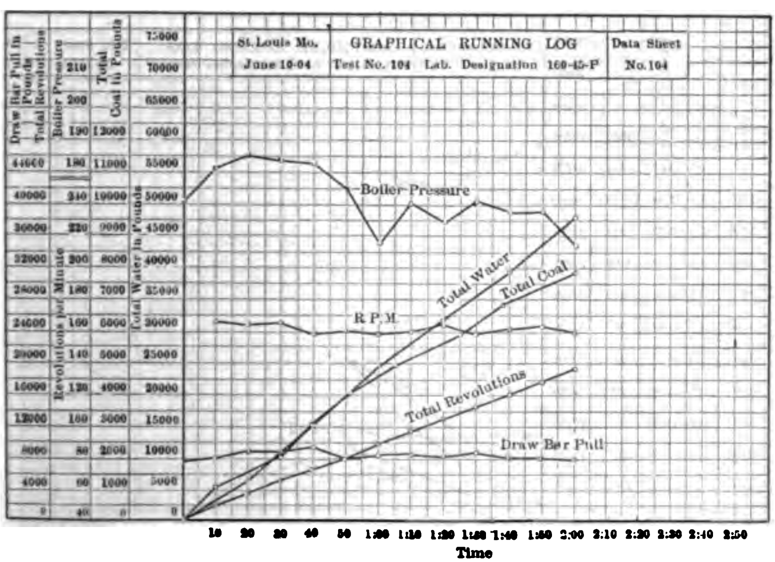
Test No. 101.



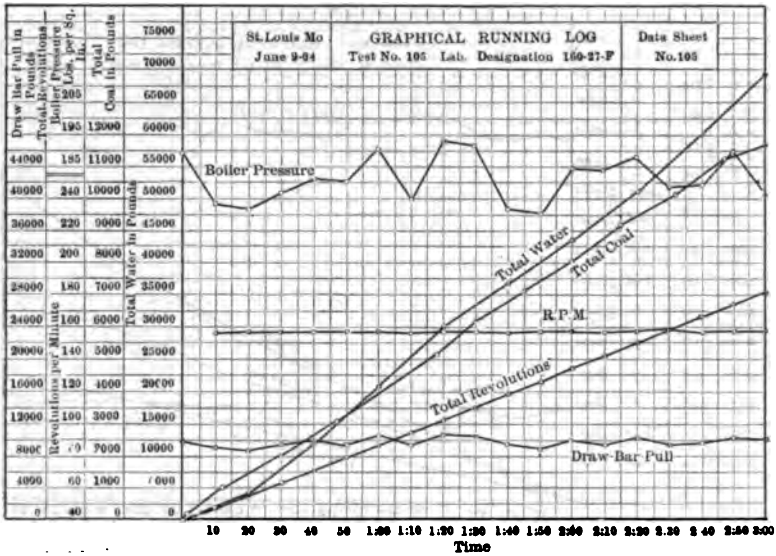
Test No. 102.



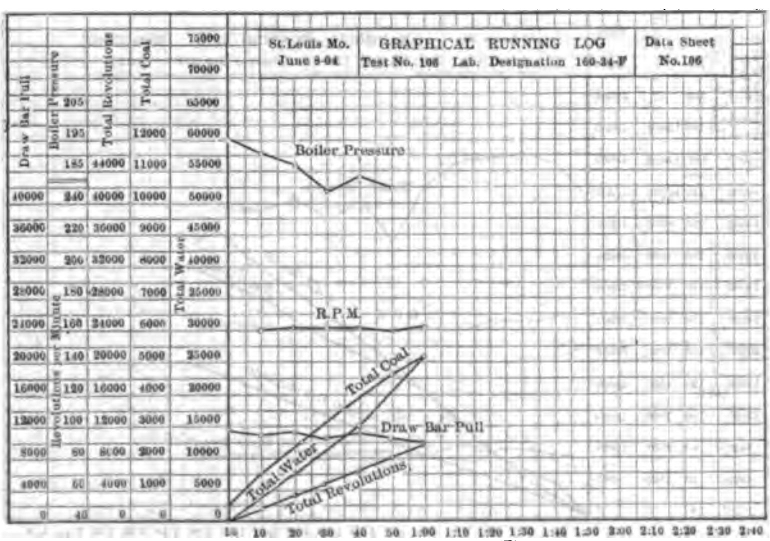
Test No. 103.



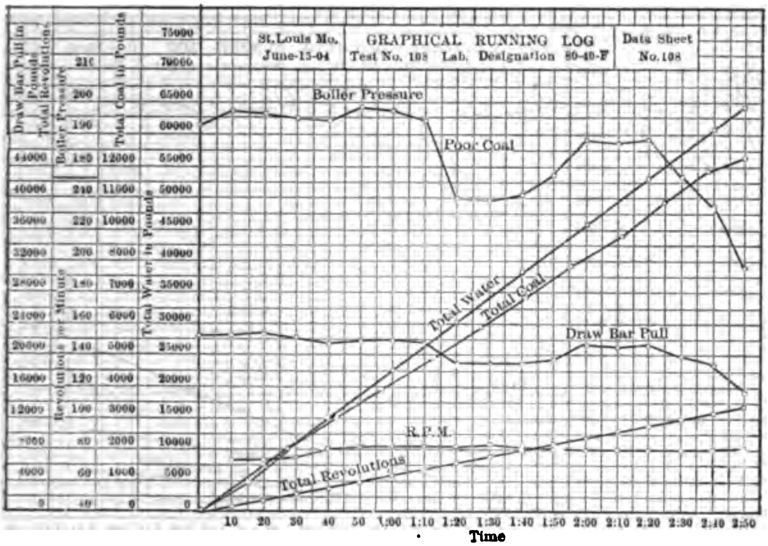
Test No. 104.



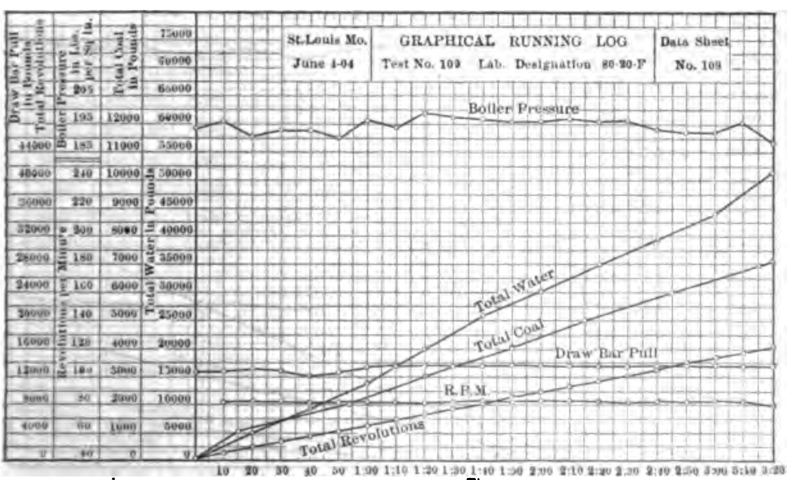
Test No. 105.



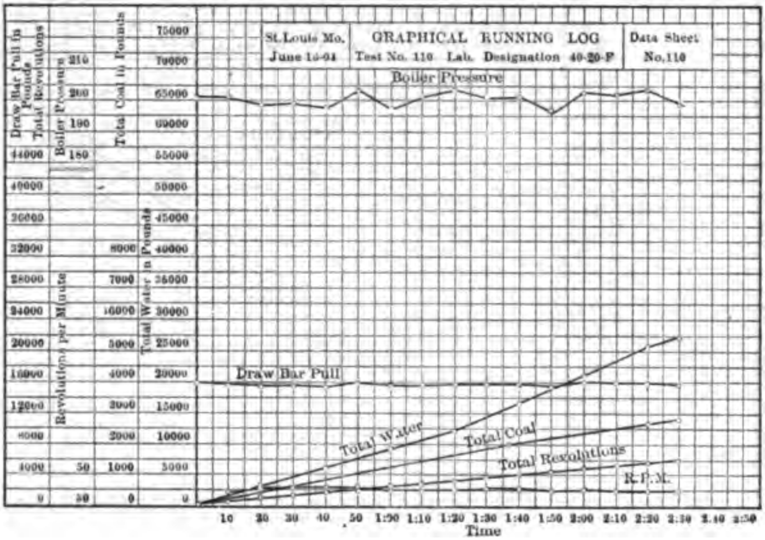
Test No. 106.



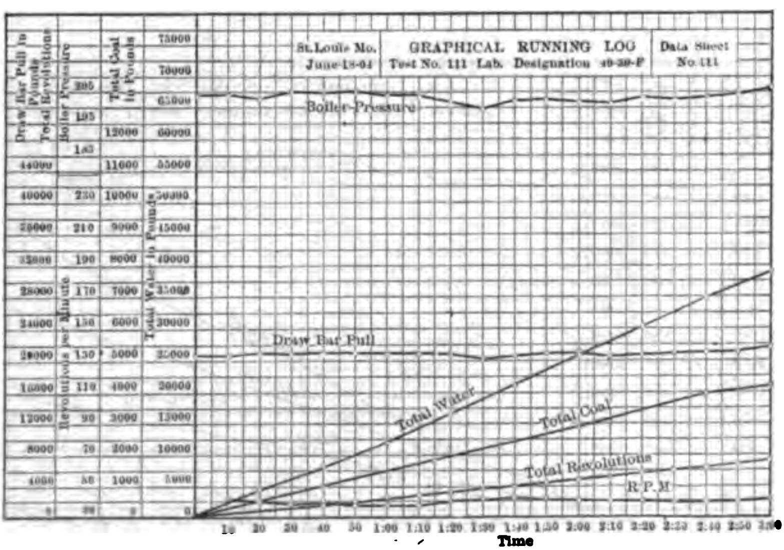
Test No. 108.



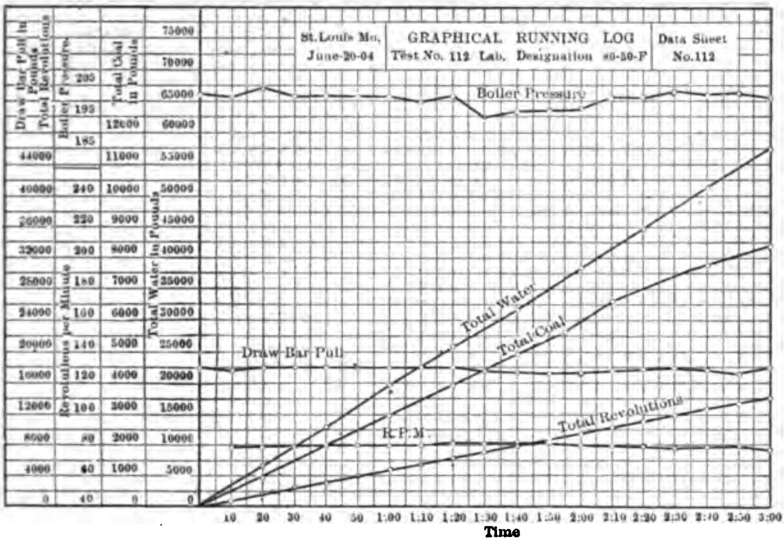
Test No. 109.



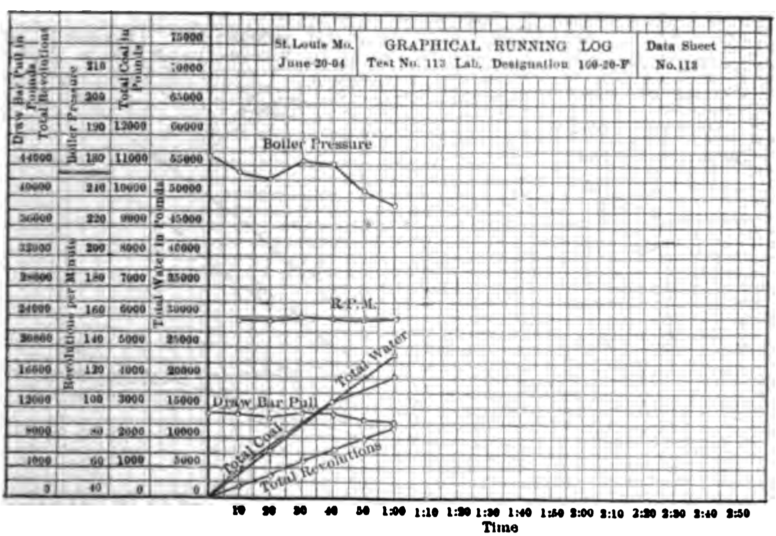
Test No. 110.



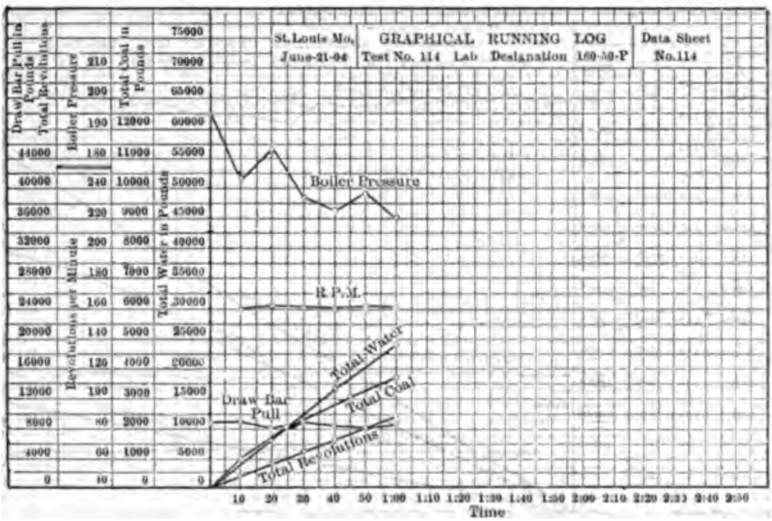
Test No. 111.



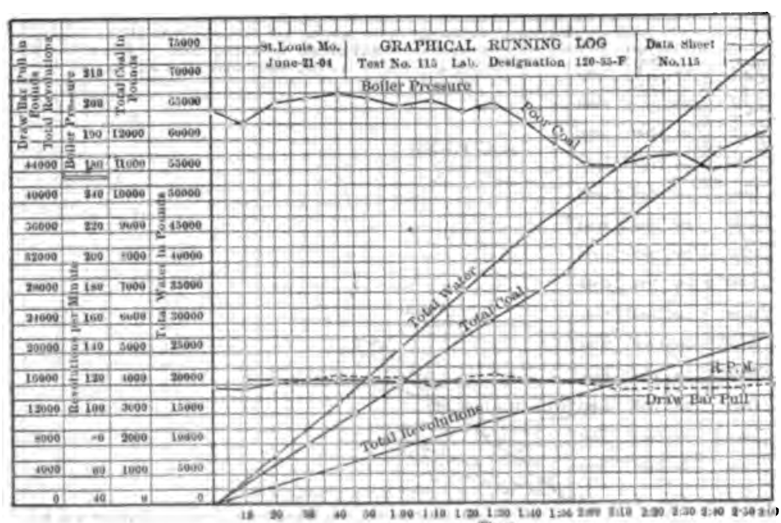
Test No. 112.



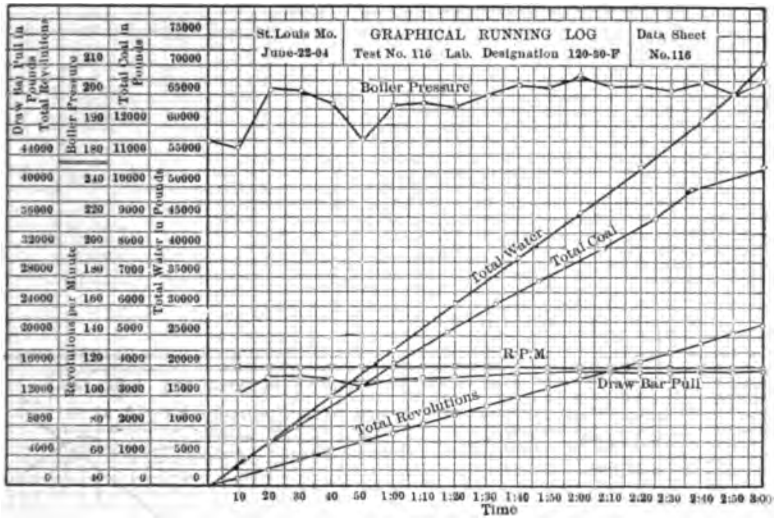
Test No. 113.



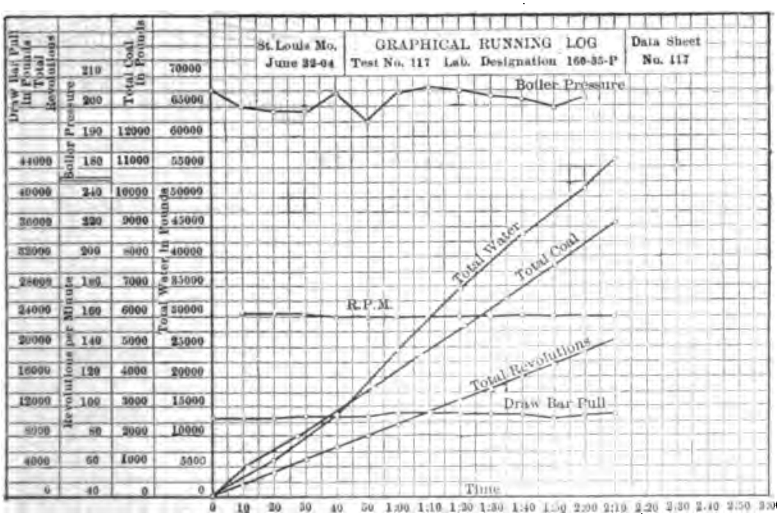
Test No. 114.



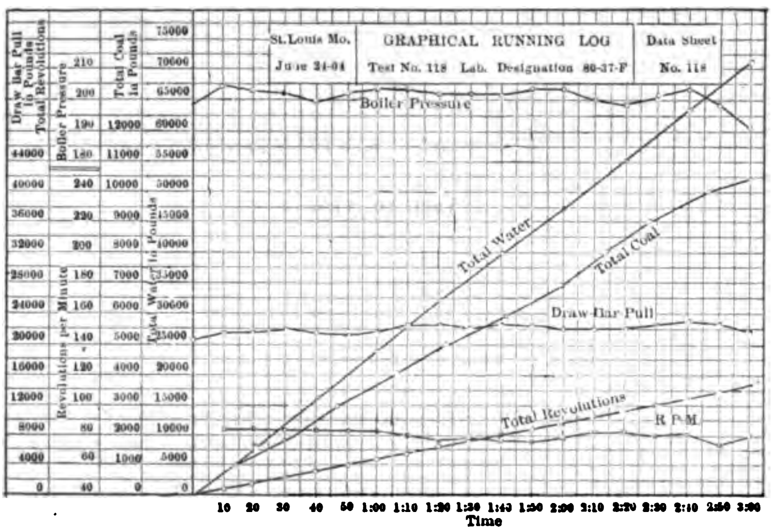
Test No. 115.



Test No. 116.

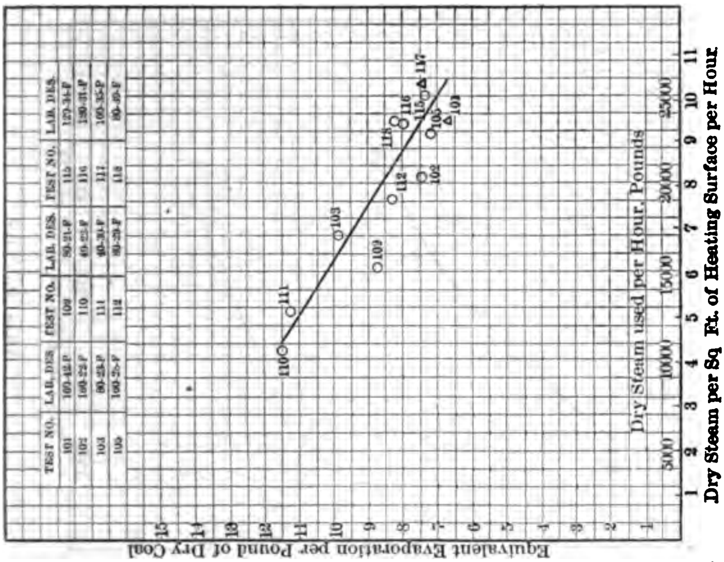


Test No. 117.

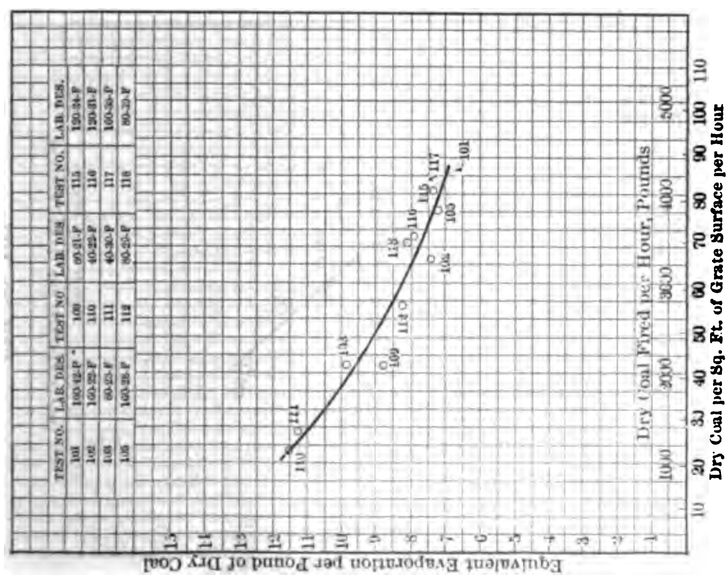


St. Louis Mo.
June 24-04
GRAPHICAL RUNNING LOG
Test No. 118 Lab. Designation 80-37-F
Data Sheet
No. 118
Draw Bar Pull in Pounds
Total Revolutions
Boiler Pressure
Revolutions per Minute
Total Coal in Pounds
Total Water in Pounds
Boiler Pressure
Total Water
Total Coal
Draw Bar Pull
Total Revolutions
R P M
Time

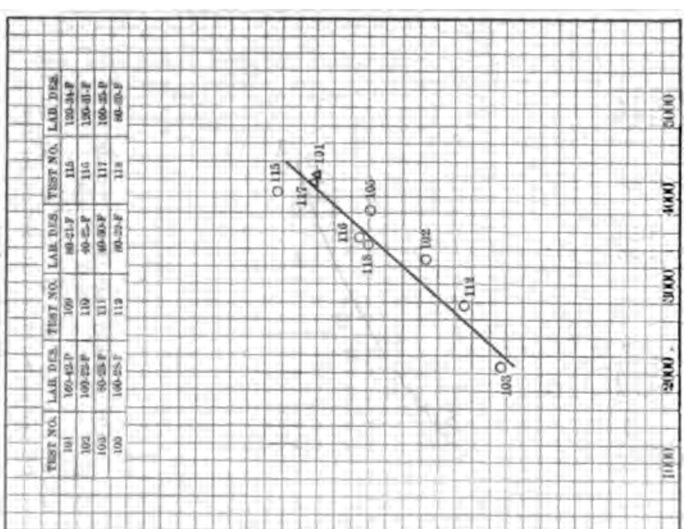
Test No. 118.



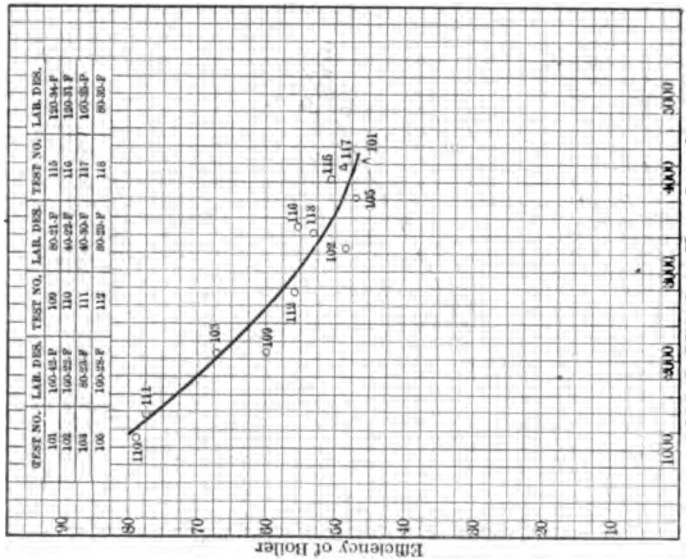
Plot No. 102.



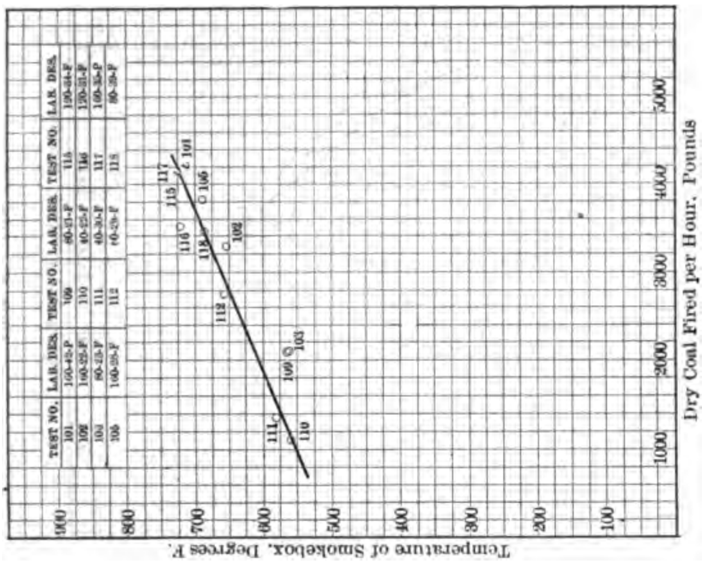
Plot No. 101.



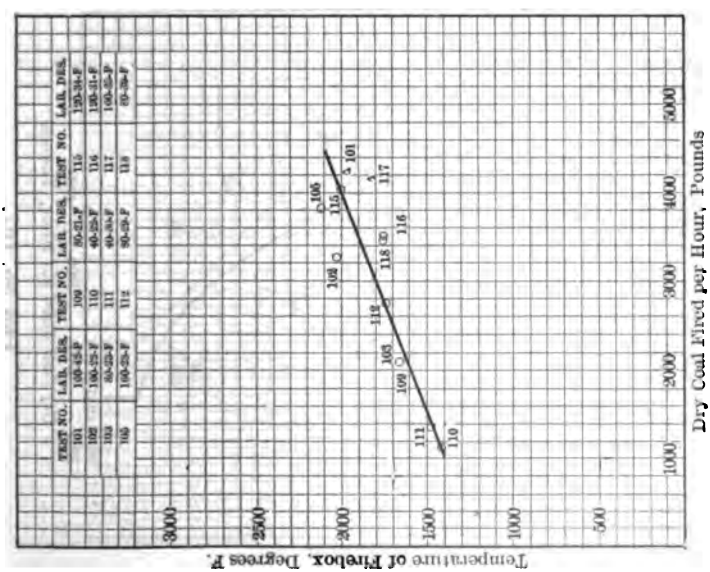
Plot No. 103.



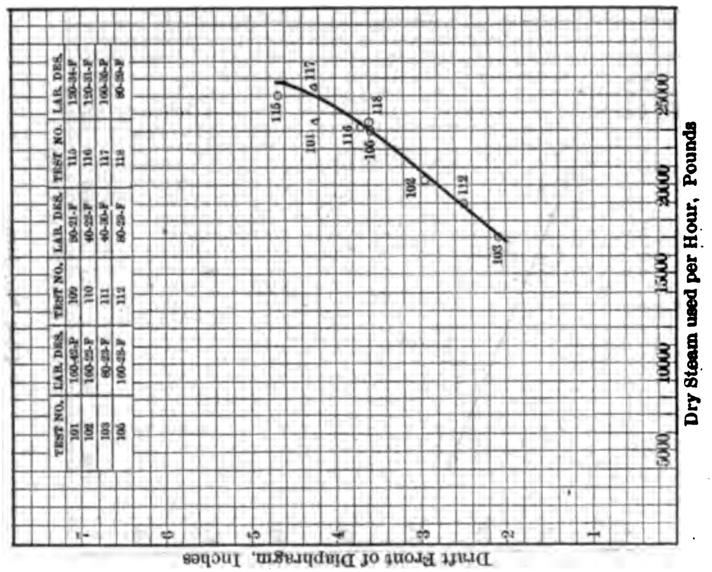
Plot No. 104.



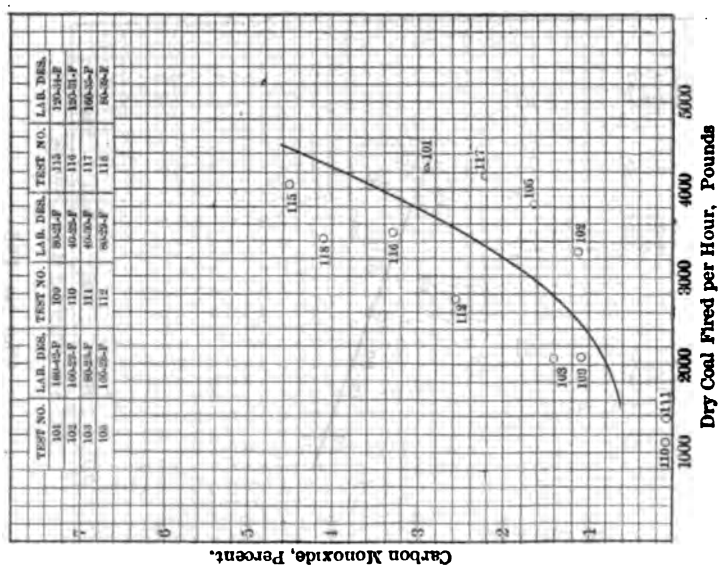
Plot No. 106.



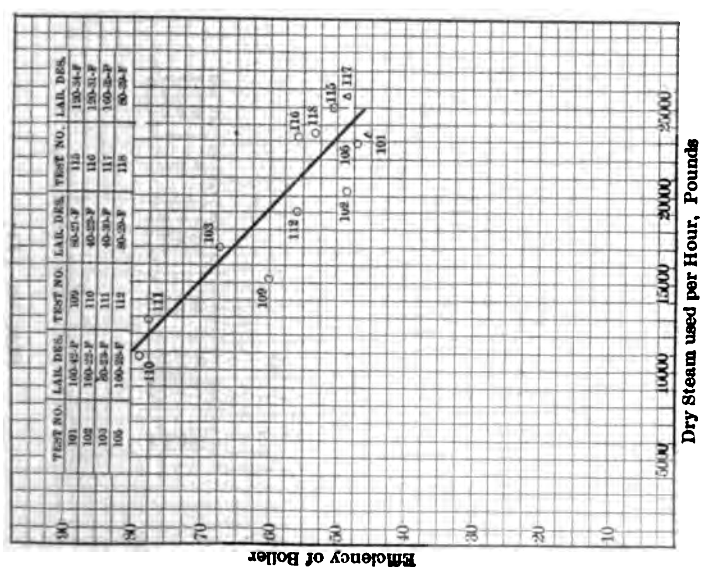
Plot No. 105.



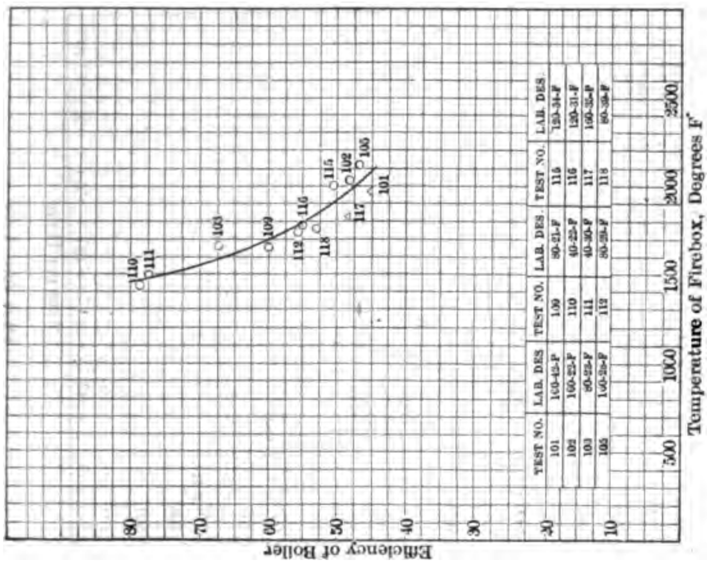
Plot No. 108.



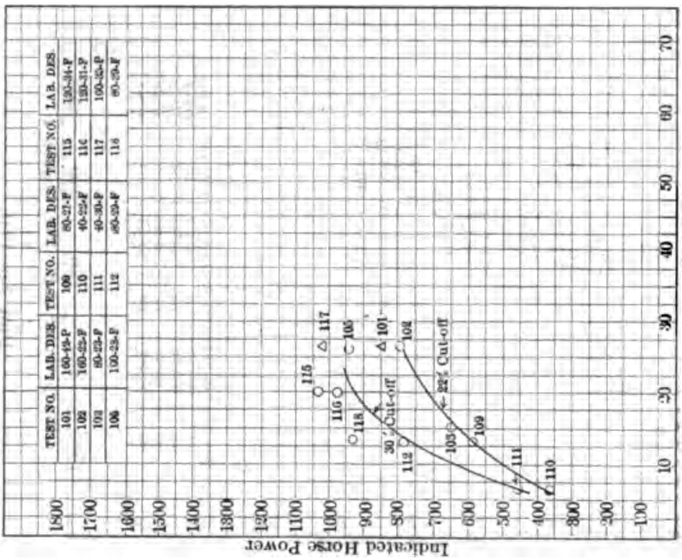
Plot No. 107.



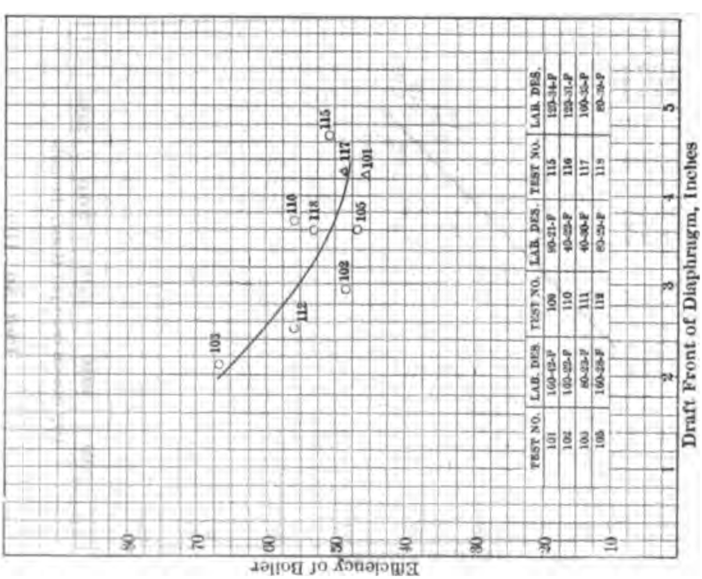
Plot No. 109.



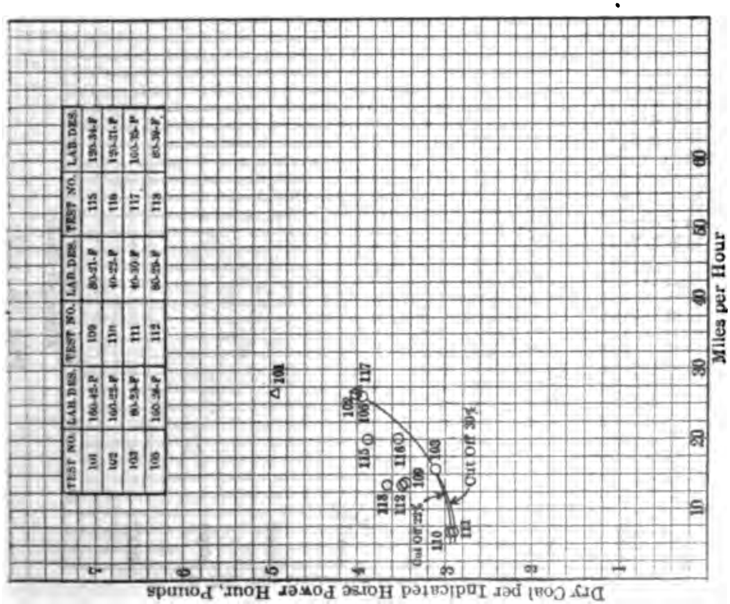
Plot No. 110.



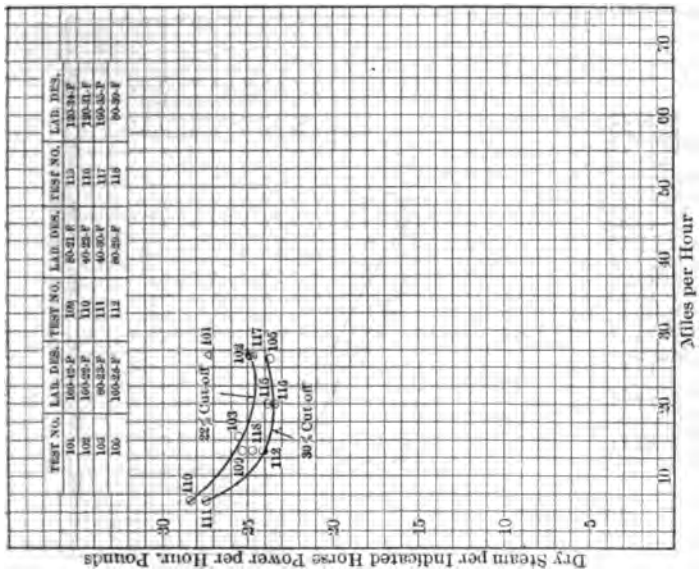
Plot No. 120.



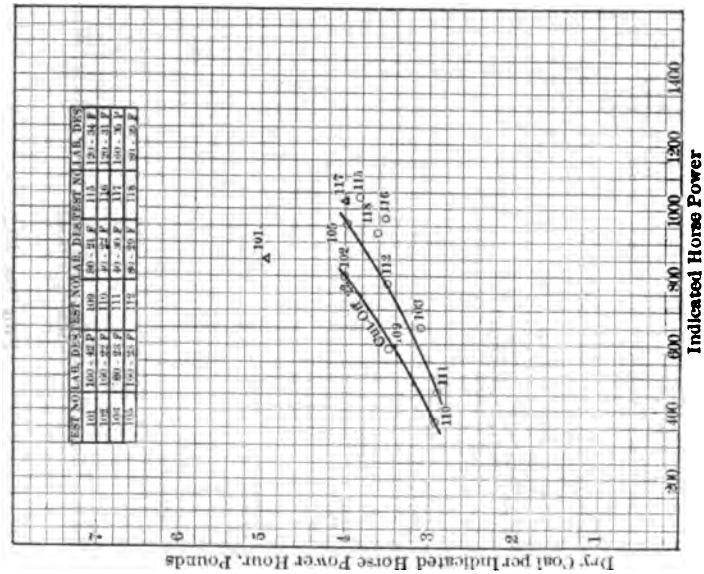
Plot No. 111.



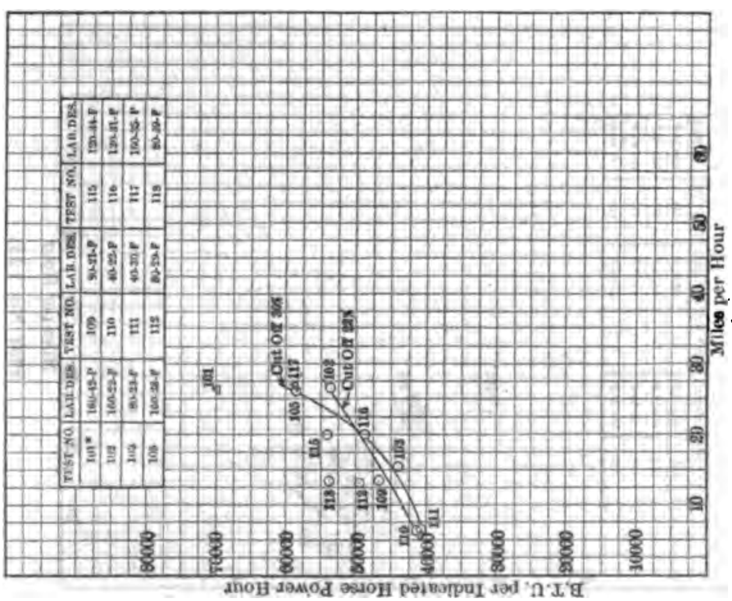
Plot No. 121.



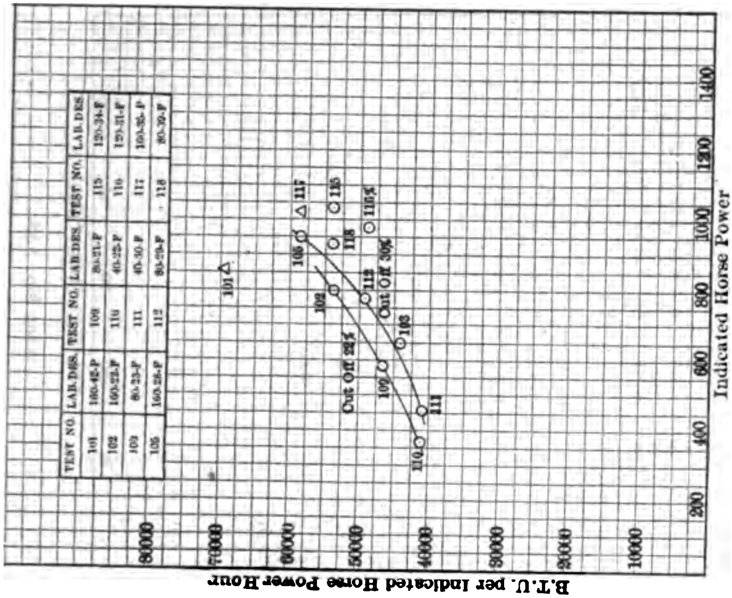
Plot No. 122.



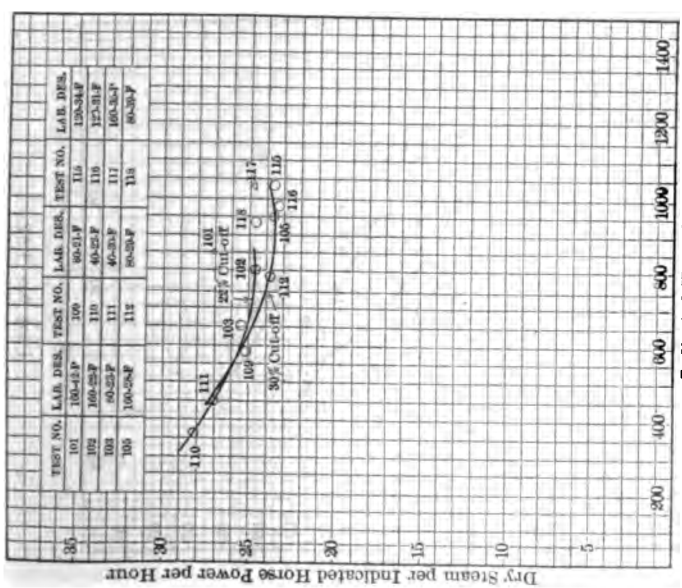
Plot No. 124.



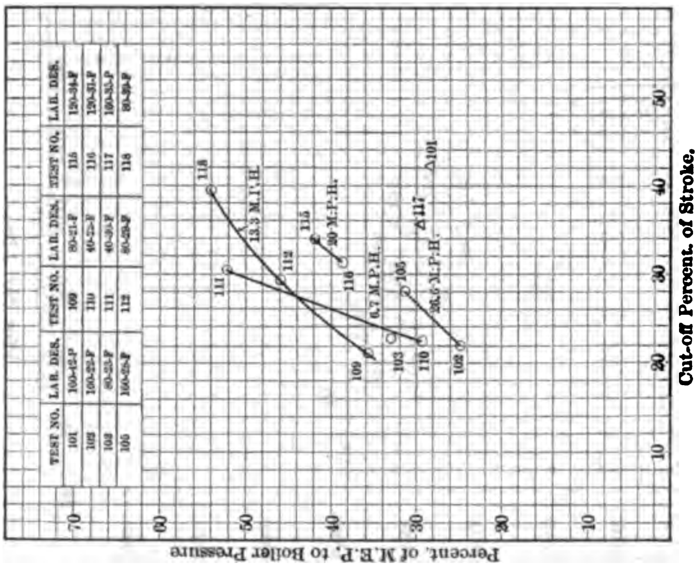
Plot No. 123.



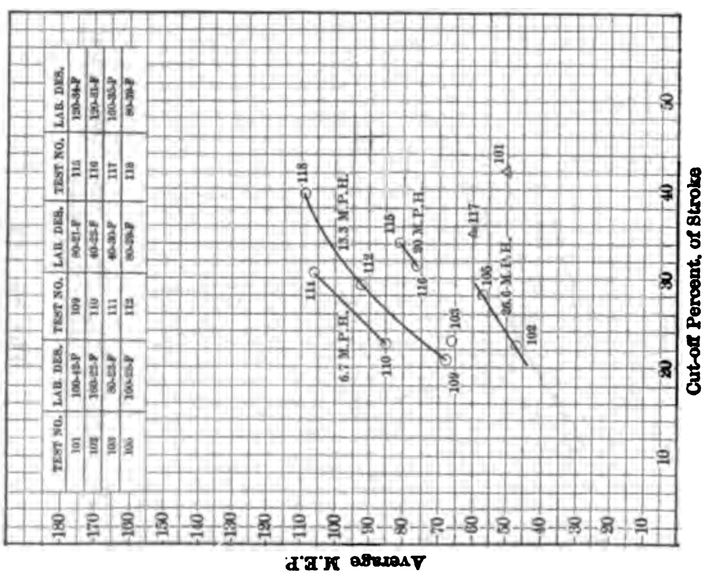
Plot No. 126.



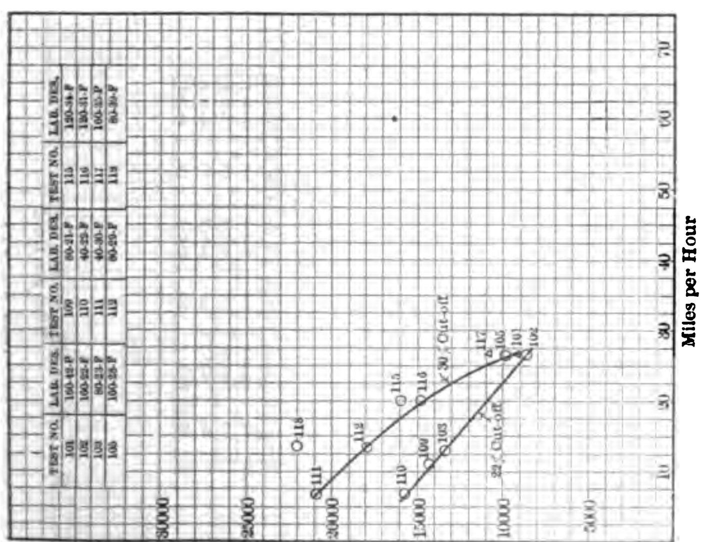
Plot No. 125.



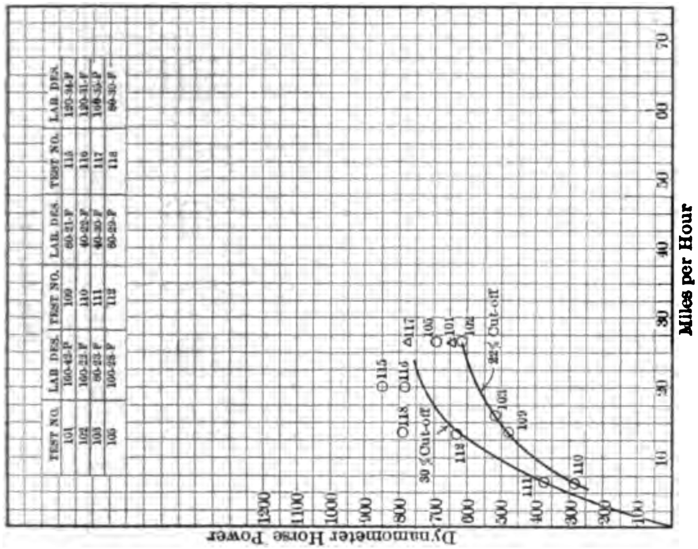
Plot No. 128.



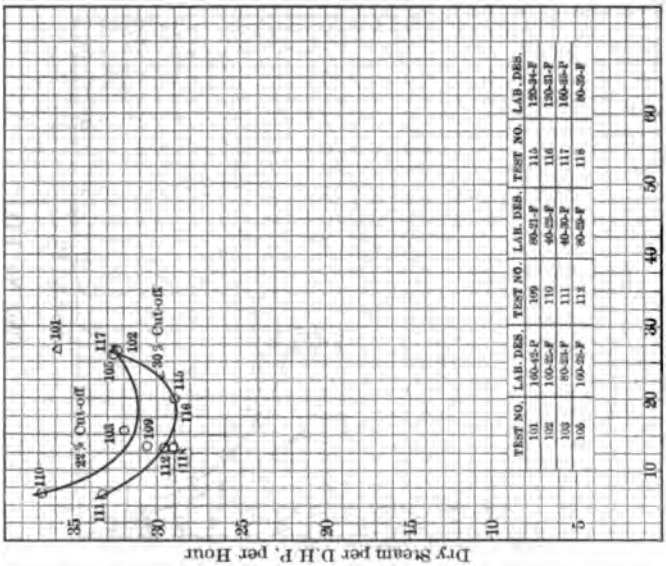
Plot No. 127.



Plot No. 140.

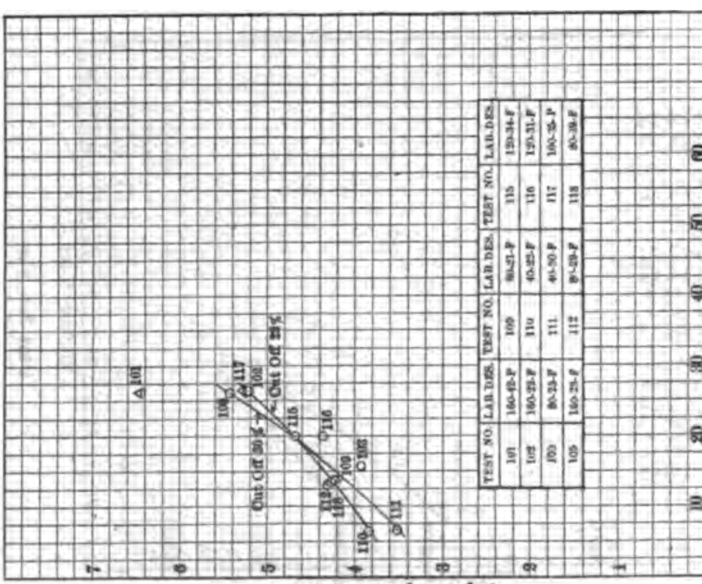


Plot No. 141.



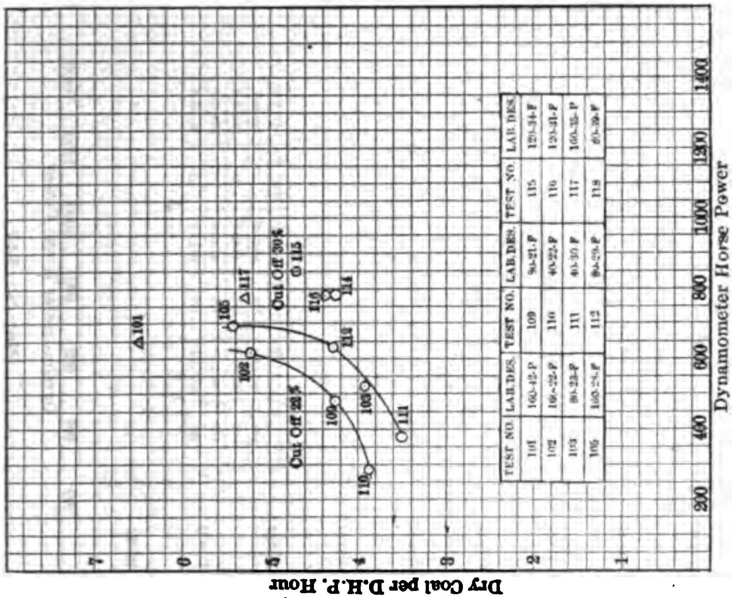
TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
101	160-42-F	109	80-21-F	115	120-34-F
102	160-25-F	110	40-25-F	116	120-51-F
103	80-23-F	111	40-30-F	117	160-35-F
106	160-28-F	112	80-29-F	118	80-39-F

Plot No. 143.

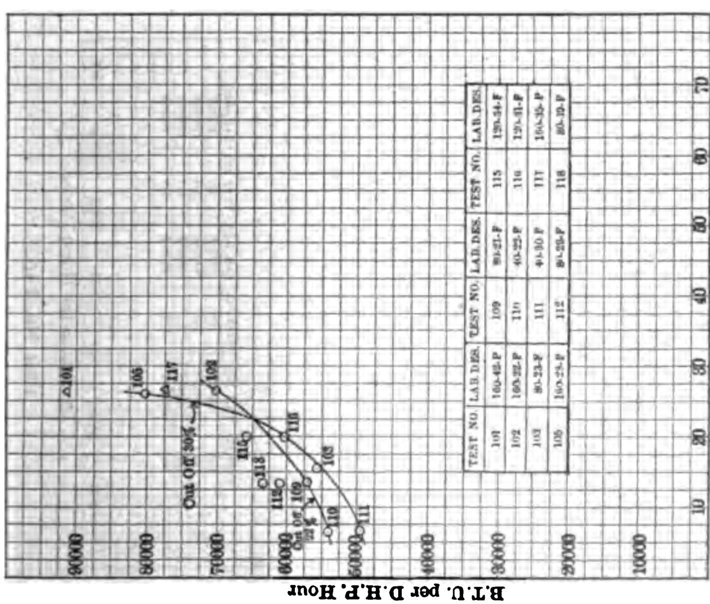


TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
101	160-42-F	109	80-21-F	115	120-34-F
102	160-25-F	110	40-25-F	116	120-51-F
103	80-23-F	111	40-30-F	117	160-35-F
105	160-25-F	112	80-29-F	118	80-39-F

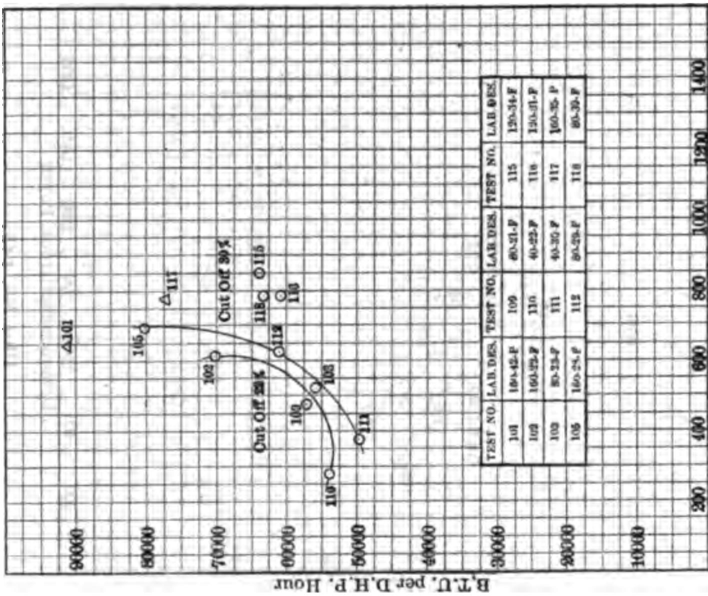
Plot No. 142.



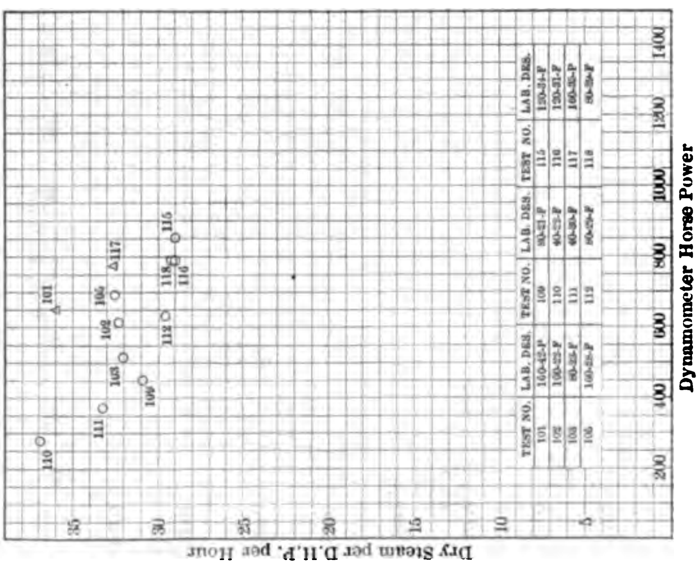
Plot No. 145.



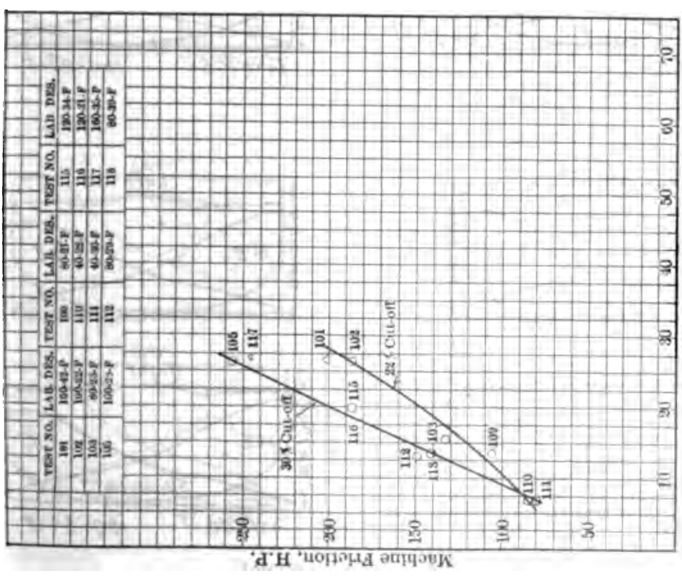
Plot No. 144.



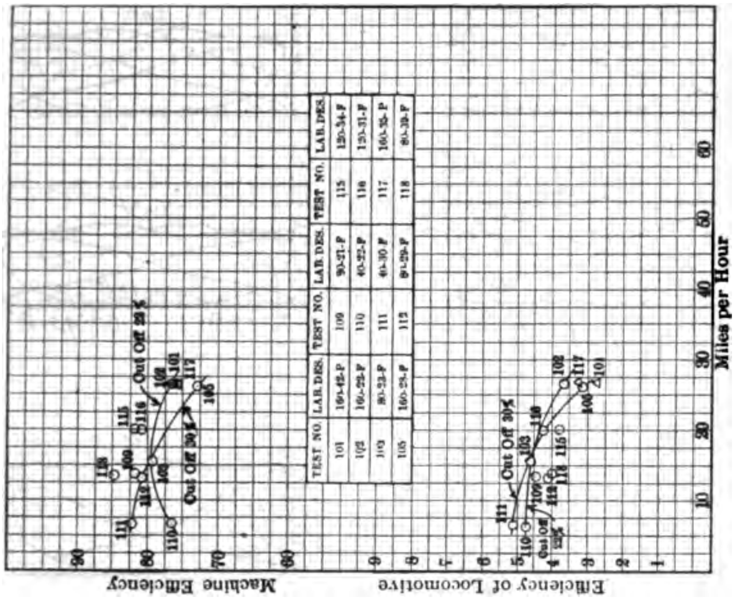
Plot No. 147.



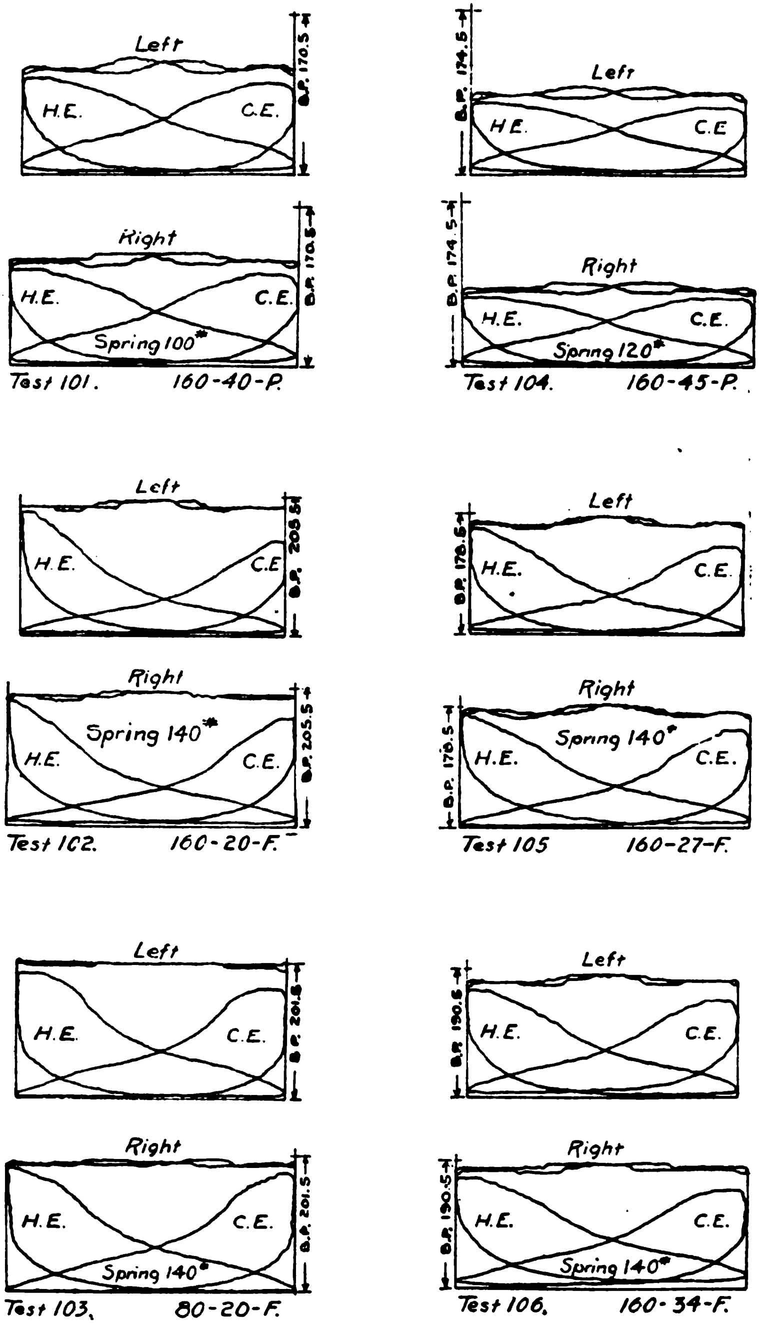
Plot No. 146.



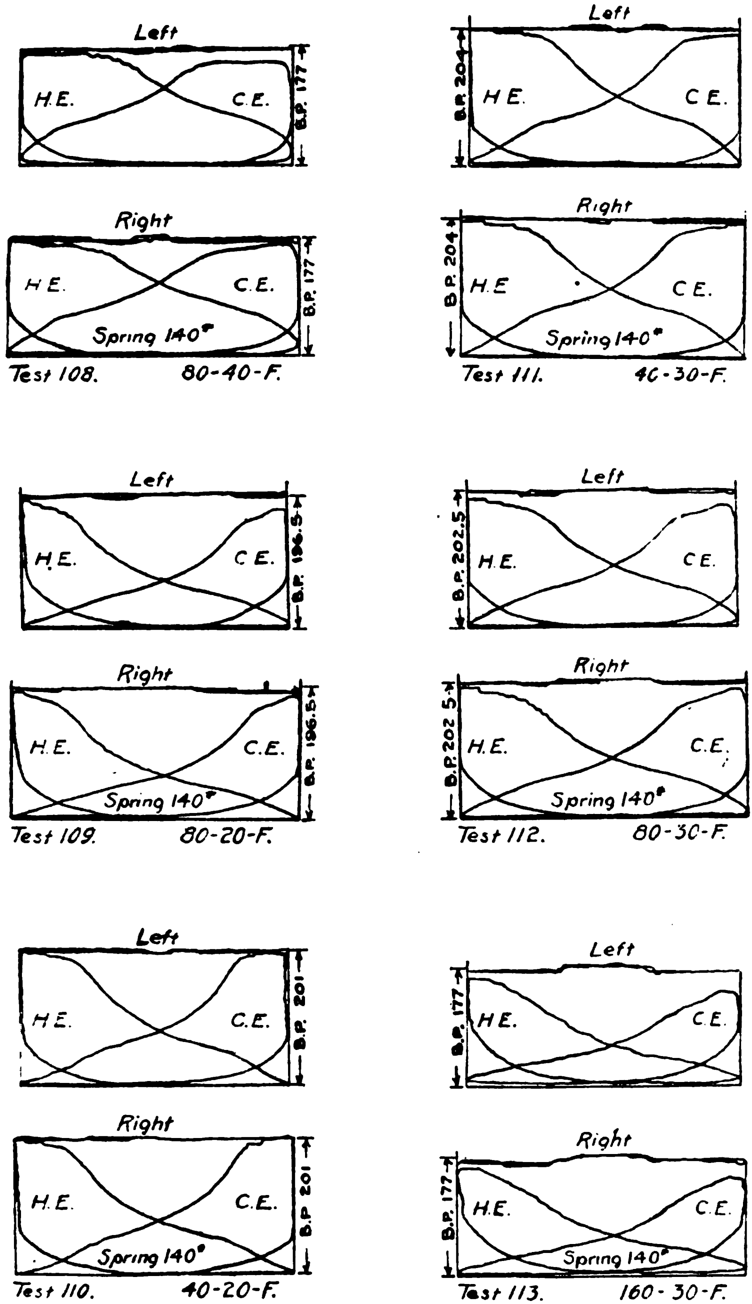
Plot No. 148.



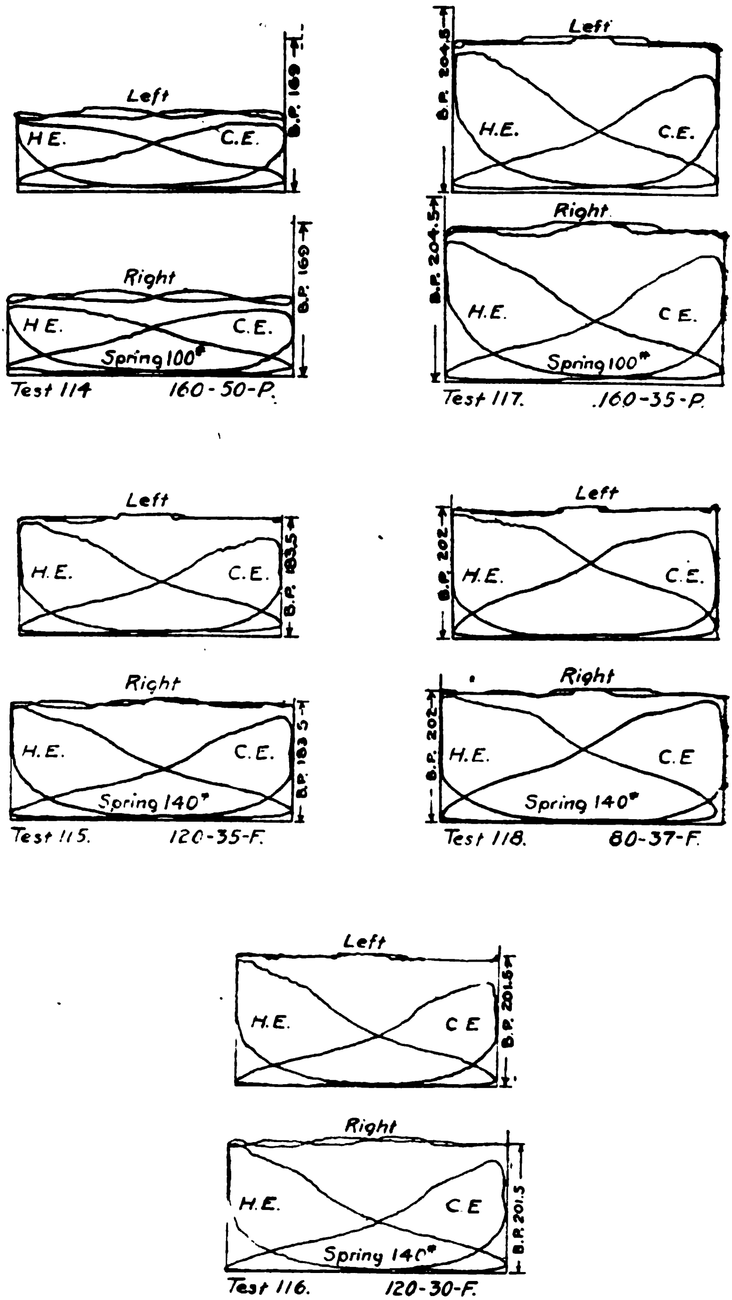
Plot No. 149.



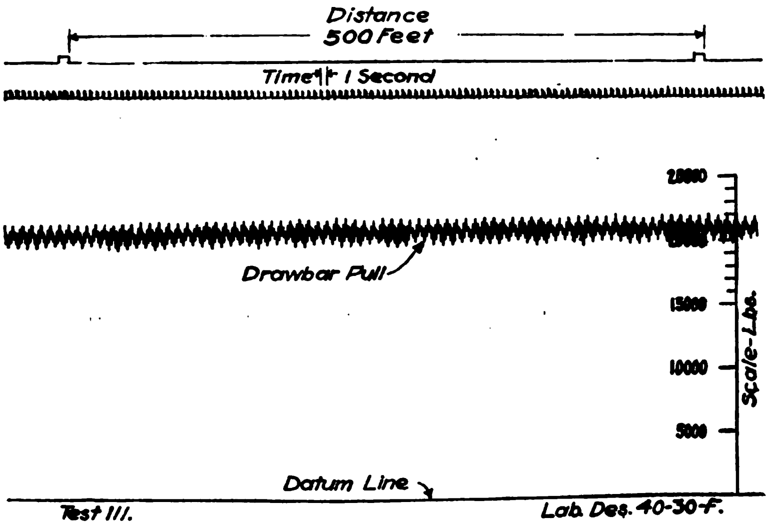
Typical Indicator Diagrams, Locomotive No. 1499.



Typical Indicator Diagrams, Locomotive No. 1499.

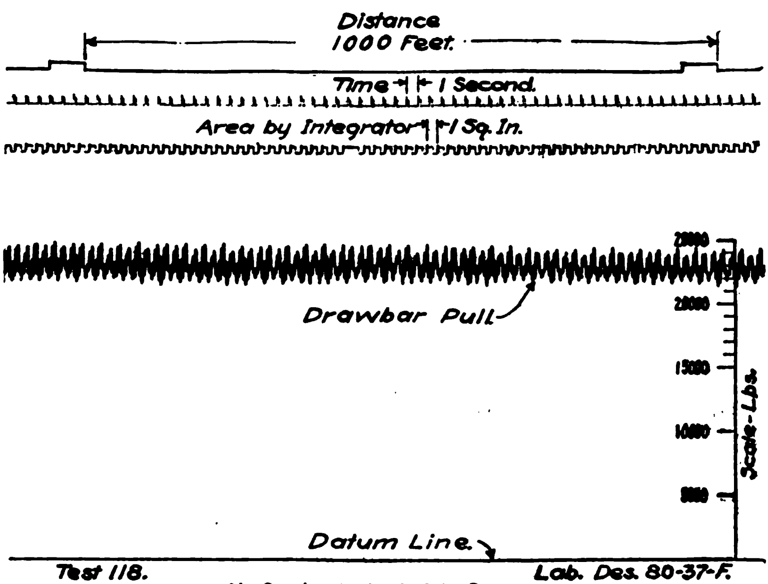


Typical Indicator Diagrams, Locomotive No. 1499.



No Dashpots in Safety Bars.

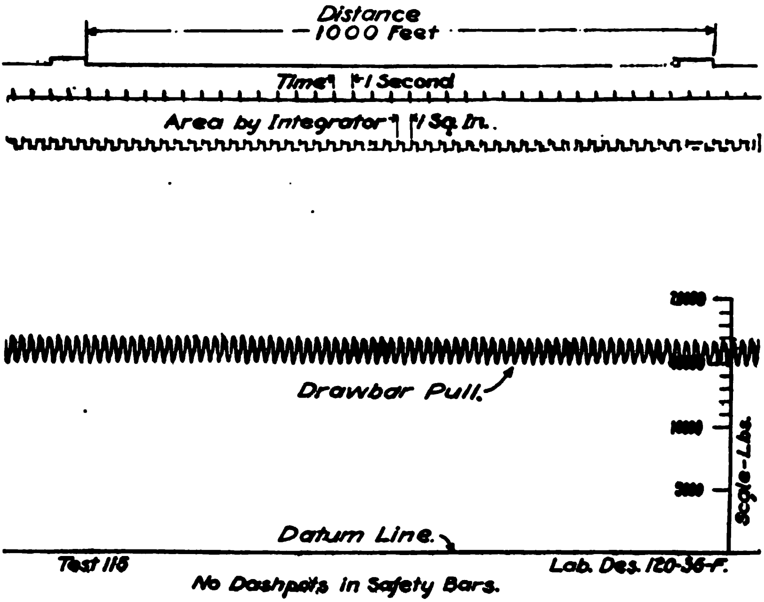
Speed, 6.7 Miles per Hour.



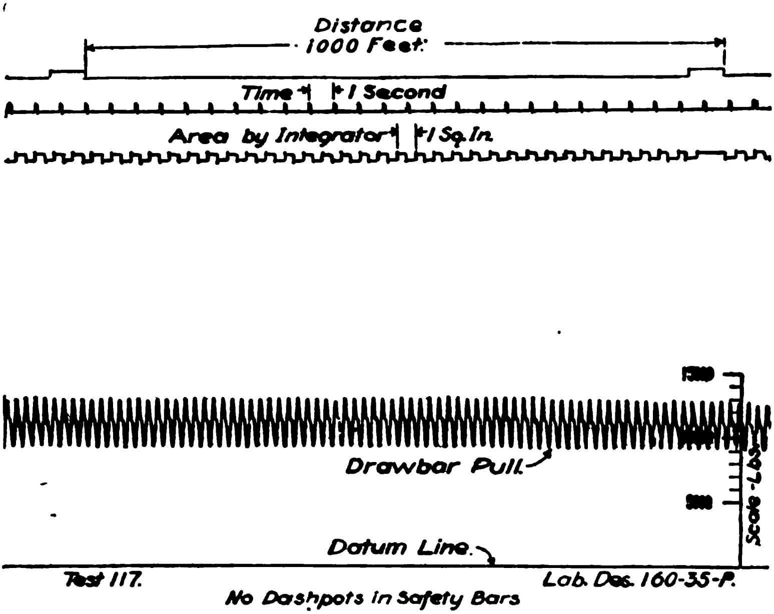
No Dashpots in Safety Bars.

Speed, 13.4 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 1499.

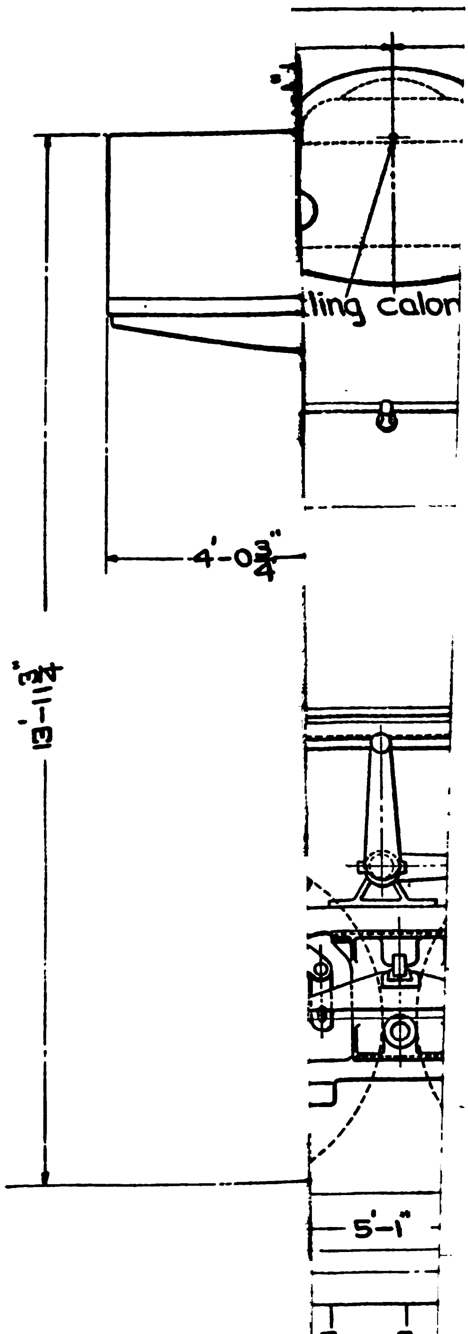


Speed, 20 Miles per Hour



Speed, 26.7 Miles per Hour

Typical Dynamometer Diagrams, Locomotive No. 1499.



ing Positio

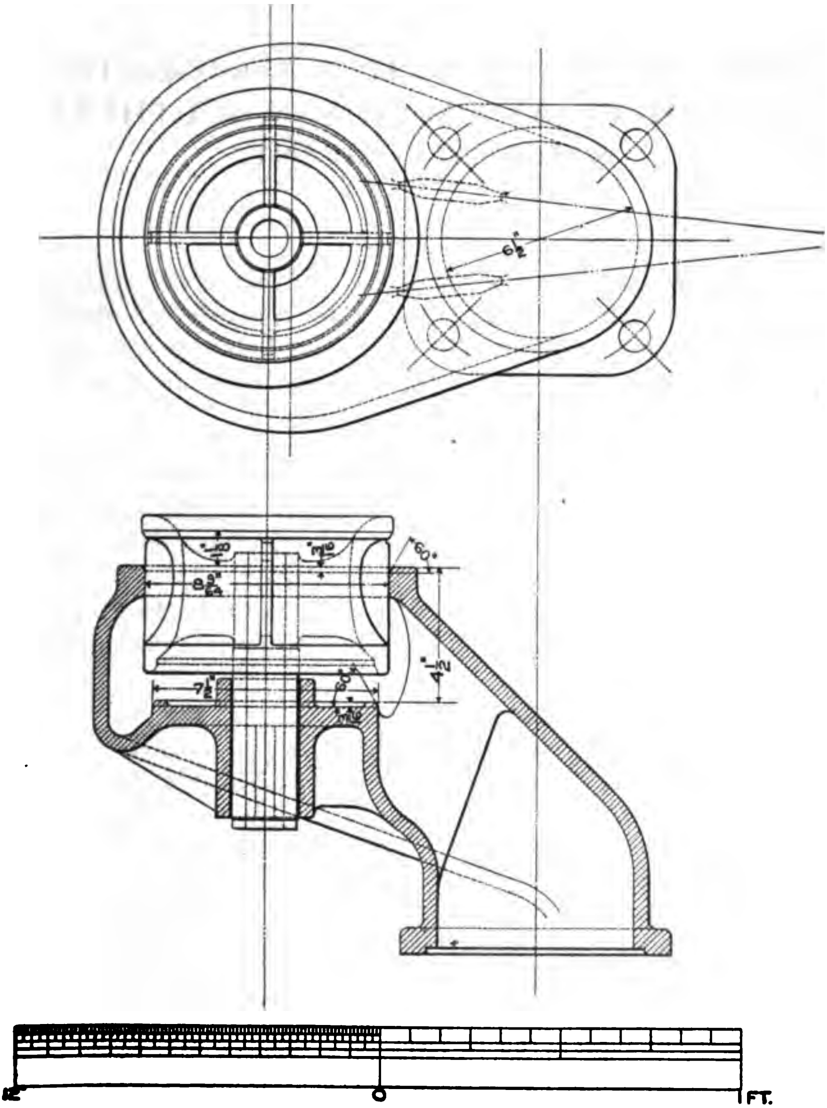


Fig. 118.—Throttle Valve, Locomotive No. 1499.

CHAPTER XIV.

TESTS OF CONSOLIDATION LOCOMOTIVE, LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

The second locomotive tested was No. 734, a two-cylinder simple locomotive, owned by the Lake Shore & Michigan Southern Railway Company, and built at the Brooks Locomotive Works. It was of the 2-8-0 type and known as class B-1 according to the railroad company's classification.

Twenty-one tests were made, the first on July 2 and the last on August 2. The total number of working days consumed in making these tests was twenty-nine, twelve of which were lost on account of difficulties experienced with the plant and six days on account of difficulties with the locomotive.

The principal dimensions and the details of the locomotive are given in Appendix 200. The principal nominal dimensions are shown in the following table:

Total weight, pounds	181,300
Weight on drivers, pounds	162,600
Cylinders (simple), inches	21 x 30
Diameter of drivers, inches	63
Fire-box heating surface, square feet	218.92
Heating surface in tubes (water side), square feet	2638.97
Total heating surface (based on water side of tubes), square feet	2857.89
*Total heating surface (based on fire side of tubes), square feet	2541.22
Grate area, square feet	33.76
Boiler pressure, pounds	200
Valves	Allen-Richardson
Link motion	Stephenson
Fire-box, type	Narrow, on top of frames

* Used in Calculations.

Number of tubes	338
Outside diameter of tubes, inches	2
Length of tubes, inches	178.94

The maximum tractive effort was 33,616 pounds, which was calculated on the assumption that 80 per cent. of the boiler pressure (200 pounds) was available as mean effective pressure at starting. On this basis the ratio of weight on drivers to maximum tractive effort was 4.84:1.

TESTS.

The tests which have been run, together with the laboratory designation and dates of running, are as follows:

TEST NO.	LABORATORY DESIGNATION.	DATE.
201	40-20-F	July 2nd.
202	40-30-F	" 7th.
203	40-40-F	" 28th.
204	80-45-F	" 27th.
205	80-20-F	" 2nd.
206	80-30-F	" 9th.
208	80-40-F	" 8th.
209	160-20-F	" 9th.
210	160-23-F	" 12th.
211	160-27-F	" 11th.
212	160-26-F	" 25th.
213	160-40-P	" 26th.
214	40-20-F	August 2nd.
215	80-20-F	" 2nd.
216	80-40-F	" 2nd.
217	160-40-P	July 15th.
218	160-40-P	" 18th.
219	160-30-P	" 23rd.
220	160-26-P	" 26th.
221	120-35-F	" 16th.
222	120-40-F	" 27th.

Owing to evident inconsistencies, shortness of tests, etc., the results obtained from tests Nos. 204, 211, 214, 215, 216, 217, 218, 221, and 222 have not been plotted on the diagrams, but the data for these tests will be found with the other data in the appendix. Some of these tests determine the maximum boiler power. Others were made to show the effect on engine friction

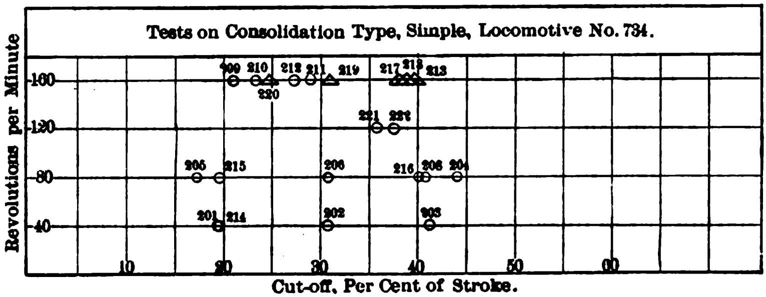


Fig. 201.

of changing the driving axle lubrication from oil to hard grease. Several tests were run at 120 revolutions per minute, to determine the draw-bar pull and a few other items.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 201.

The tests are arranged in order, according to the rate of equivalent evaporation. It will be noted that two plotted tests were 129 and 130 minutes; all the rest were 180 minutes in duration.

TABLE No. 201—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. of Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
201	40–20–F	180	192.8	14.605	68.7	73.8	99.3
202	40–30–F	180	199.9	14.474	80.7	72.8	126.5
205	80–20–F	180	200.3	14.606	71.8	73.7	159.5
203	40–40–F	180	199.6	14.513	74.3	76.0	131.5
206	80–30–F	180	201.8	14.466	76.0	73.0	245.4
209	160–20–F	180	201.5	14.449	83.5	73.6	308.5
220	160–26–P	180	201.6	14.509	74.6	76.3	353.6
219	160–30–P	180	200.7	14.551	77.6	77.3	365.6
210	160–23–F	129	198.5	14.405	75.4	74.7	263.5
208	80–40–F	180	204.0	14.462	78.9	72.8	373.2
213	160–40–P	180	202.6	14.485	75.6	76.4	405.4
212	160–26–F	180	199.4	14.543	80.2	76.4	420.0

The lowest average boiler pressure was 192.8 pounds, while the highest was 204 pounds. The temperature of the feed water was very uniform. In the majority of tests more than 200 pounds of coal per square foot of grate were fired. Only four of the tests fell below 200 pounds. The total coal fired per square foot of grate area follows:

In 4 tests .... between 100 and 200 pounds.
In 2 tests .... between 200 and 300 pounds.
In 4 tests .... between 300 and 400 pounds.
In 2 tests .... more than 400 pounds.

EVAPORATION—TABLE 202.

The evaporation per hour was between the limits of 9,381 pounds and 25,882 pounds.

TABLE No. 202—EVAPORATION.

Identification of Test		Duration of Test, Minutes	Water and Steam		Calorimeter Results			Equivalent Evaporation Lbs. Per Hour
Test Number	Laboratory Designation		Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Quality of steam in Branch Pipe	Degrees Superheat in Branch Pipe	
		Cal.	264	340	*228	229	230	344
201	40-20-F	180	28144	9381	.9860	——	——	11122
202	40-30-F	180	38274	12758	.9871	.9915	0	15162
205	80-20-F	180	42709	14236	.9849	——	——	16864
203	40-40-F	130	34037	15713	.9856	.9919	0	18599
206	80-30-F	180	59580	19860	.9865	.9978	0	23580
209	160-20-F	180	67638	22546	.9871	.9928	0	26780
220	160-26-P	180	71681	23893	.9861	.9954	0	28280
219	160-30-P	180	72841	24280	.9855	1.0053	9.50	28712
210	160-23-F	129	52049	24207	.9868	.9959	0	28713
208	80-40-F	180	74508	24836	.9837	.9949	0	29453
213	160-40-P	180	75376	25125	.9855	1.0082	14.74	29710
212	160-26-F	180	77646	25882	.9856	.9964	0	30620

The moisture in the steam at the dome did not exceed 1.6 per cent. It will also be seen that the rate of evaporation did not apparently affect the quality of the steam in the dome.

BOILER POWER—TABLE 203.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 329 to 907.

The equivalent evaporation per square foot of heating surface ranged from 4.38 to 12.05 pounds per hour.

The maximum boiler horse power developed was 887.5, the horse power being calculated on the usual basis of 34.5 evaporative units per horse power.

The horse power developed per square foot of heating surface ranged from .127 to .349.

TABLE No. 203—BOILER POWER.

Identification of Test		Duration of Test, Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft of Grate Surface
		Cal.	Cal.	345	349	Cal.	Cal.
201	40–20–F	180	329	4.38	322.4	.127	9.55
202	40–30–F	180	449	5.97	439.5	.173	13.02
205	80–20–F	180	500	6.64	488.8	.192	14.48
203	40–40–F	130	551	7.32	539.1	.212	15.97
206	80–30–F	180	698	9.28	683.5	.269	20.25
209	160–20–F	180	793	10.54	776.2	.305	22.99
220	160–26–P	180	838	11.13	819.7	.323	24.28
219	160–30–P	180	850	11.29	832.2	.327	24.65
210	160–23–F	129	851	11.30	832.2	.327	24.65
208	80–40–F	180	872	11.59	853.7	.336	25.29
218	160–40–P	180	880	11.69	861.2	.339	25.51
212	160–26–F	180	907	12.05	887.5	.349	26.29

The maximum horse power developed per square foot of grate surface was equivalent to about one horse power for each .038 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 204.

The total dry coal fired, ranged from 3,328 pounds to 14,084 pounds, and the amount per hour from 1,109 pounds to 4,695 pounds.

The dry coal fired per square foot of grate area per hour, ranged from 32.85 pounds to 139.04 pounds. The increase in the rate of combustion follows closely that of the evaporation.

The coal fired per square foot of heating surface per hour ranged from .436 to 1.847 pounds.

CINDERS AND SPARKS—TABLE 205.

In the light power tests nearly all the sparks ejected from the stack were caught in the trap and weighed, but in tests with strong

TABLE No. 204—COAL AND RATE OF COMBUSTION.

Identification of Test				Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation	Duration of Test, Minutes	Total Dry Coal Fired	Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq.Ft. of Grate Per Hour	Dry Coal Per Sq.Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
201	40–20–F	180	3328	3128	1109	1043	32.85	.436
202	40–30–F	180	4236	3949	1412	1316	41.82	.556
205	80–20–F	180	5344	4968	1781	1656	52.75	.701
203	40–40–F	130	4389	4104	2027	1895	60.03	.798
206	80–30–F	180	8188	7720	2729	2573	80.83	1.074
209	160–20–F	180	10304	9691	3435	3230	101.73	1.352
220	160–26–P	180	11851	11190	3950	3730	117.03	1.554
219	160–30–P	180	12238	11559	4079	3853	120.83	1.605
210	160–23–F	129	8808	8314	4096	3867	121.33	1.612
208	80–40–F	180	12456	11638	4152	3879	122.97	1.634
213	160–40–P	180	13515	12657	4505	4219	133.43	1.773
212	160–26–F	180	14084	13202	4695	4401	139.04	1.847

TABLE No. 205—CINDERS AND SPARKS.

Identification of Test			Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation	Duration of Test, Minutes	Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
201	40–20–F	180	0.0	50.0	50.0	10124	9244
202	40–30–F	180	30.0	91.6	121.6	11004	8143
205	80–20–F	180	0.0	49.6	49.6	——	9684
203	40–40–F	130	33.7	129.7	163.4	11884	11664
206	80–30–F	180	15.0	239.6	254.6	12105	11884
209	160–20–F	180	17.6	300.3	317.9	11774	11665
220	160–26–P	180	16.3	328.3	344.6	12325	12104
219	160–30–P	180	19.6	326.6	346.2	12325	11885
210	160–23–F	129	25.6	401.9	427.5	12325	11884
208	80–40–F	180	13.0	334.3	347.3	12325	11775
213	160–40–P	180	34.3	339.6	373.9	12325	11884
212	160–26–F	180	17.6	353.3	370.9	12104	12104

draft a large part of the sparks escaped. The quantities, therefore, are not strictly accurate, especially for the high power tests.

The maximum calorific value of the cinders was 12,325 B. T. U., and the maximum calorific value of the sparks was 12,104 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 206.

The general description which has been given under this heading for locomotive No. 1499 also applies here, so that table 206 and Figs. 202, 203, and 204 need little explanation. This locomotive did not have any movable dampers in the ash pan. The combined area of the ash pan openings was 4.88 square feet, or 0.14 of a square foot per square foot of grate area. The ash pan draft was relatively low.

TABLE No. 206—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water				Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In Front of Diaphragm	Back of Diaphragm	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	223	224	225	212	207	339
201	40-20-F	180	1.88	.19	——	.25	1885	513	32.85
202	40-30-F	180	2.38	.93	.70	.42	1924	530	41.82
205	80-20-F	180	2.90	.62	——	.22	2000	573	52.75
203	40-40-F	180	3.06	1.36	.85	.10	1992	551	60.08
206	80-30-F	180	4.15	2.12	1.12	.20	1938	607	80.83
209	160-20-F	180	4.89	2.31	1.20	.15	1945	628	101.78
220	160-26-P	180	5.35	2.68	.80	.18	2312	640	117.08
219	160-30-P	180	5.02	2.78	1.12	.15	2221	654	120.83
210	160-23-F	129	5.33	2.79	1.21	.23	2203	651	121.33
208	80-40-F	180	5.85	2.84	1.26	.20	2152	650	122.97
213	160-40-P	180	5.85	2.98	1.08	.16	2220	669	133.43
212	160-26-F	180	5.91	3.21	.97	.15	2162	667	139.04

The fire-box temperature ranged from 1,885 to 2,312 degrees and the smoke-box temperature from 513 to 669 degrees Fahr. As the rate of combustion increased, the increase in temperature of both the fire-box and smoke-box was nearly the same number of degrees.

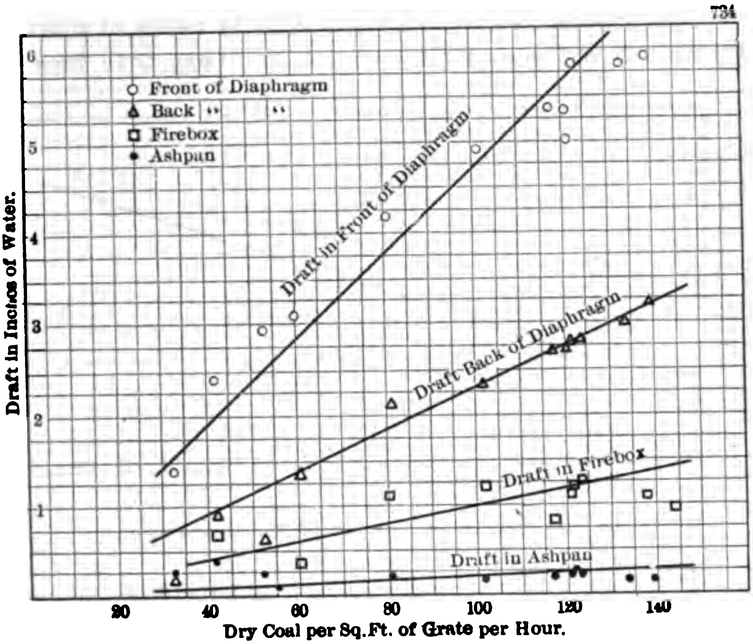


Fig. 202.— Draft and Rate of Combustion.

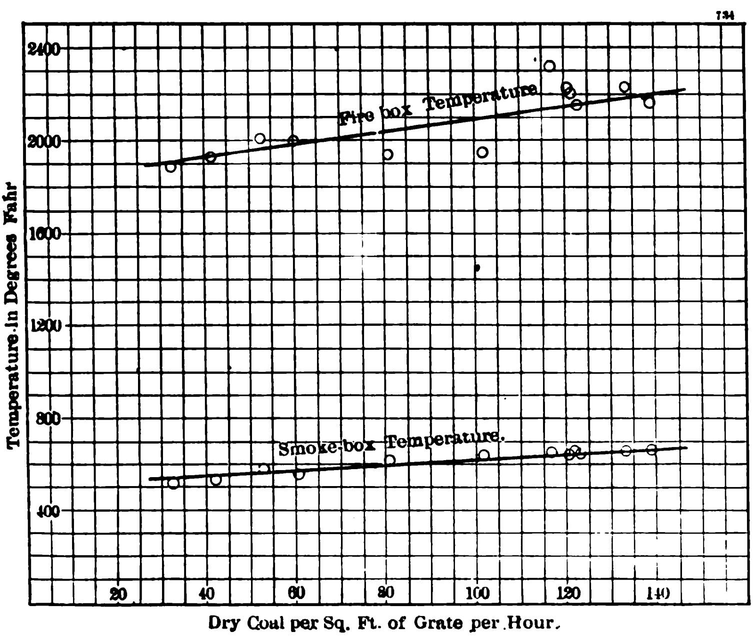


Fig. 203.— Fire-box and Smoke-box Temperatures.

The relations shown in Chapter XIII by means of equations 101 to 108 inclusive, for locomotive No. 1499, have been ob-

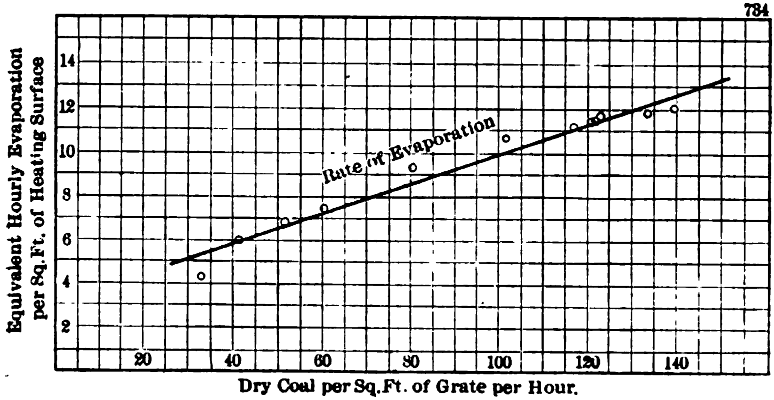


Fig. 204.—Rates of Combustion and Evaporation.

tained for this locomotive in like manner, and, therefore, are given below without further explanation.

From Fig. 202;

$D = .047\,G$ .... (201)

From Fig. 203;

$T_f = 2.83G + 1815$ .... (202)

$T_s = 1.27G + 490$ .... (203)

$T_f - T_s = 1.56G + 1325$ .... (204)

From Fig. 204;

$H = .069G + 3$ .... (205)

From equation (204);

$G = .641\ (T_f - T_s) - 849.3$ .... (206)

From equation (205);

$G = 14.49\ H - 43.4$ .... (207)

From equations (206) and (207);

$H = .0442\ (T_f - T_s) - 55.6$ .... (208)

EVAPORATIVE PERFORMANCE—TABLE 207.

The equivalent evaporation per pound of dry coal ranged from 10.74 pounds to 6.52 pounds.

The heating value of the coal remained practically unchanged.

TABLE No. 207—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
201	40–20–F	180	8.40	10.03	10.66	14854	65.20
202	40–30–F	180	8.96	10.74	11.52	14537	71.34
205	80–20–F	180	7.93	9.47	10.18	14865	61.53
203	40–40–F	130	7.67	9.18	9.82	15132	58.57
206	80–30–F	180	7.19	8.64	9.16	14818	56.32
209	160–20–F	180	6.49	7.71	8.29	14795	50.90
220	160–26–P	180	6.00	7.16	7.58	15187	45.52
219	160–30–P	180	5.90	7.03	7.45	15094	45.08
210	160–23–F	129	5.85	7.01	7.43	14794	45.74
208	80–40–F	180	5.91	7.09	7.59	14803	46.28
213	160–40–P	180	5.51	6.60	7.04	14943	42.62
212	160–26–F	180	5.48	6.52	6.96	15067	41.81

TABLE No. 208—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
201	40–20–F	180	8.40	.07	10.62	80.91	14746	.38
202	40–30–F	180	7.60	0	11.07	81.33	14416	0
205	80–20–F	180	7.97	0	10.73	81.30	14746	0
203	40–40–F	130	6.90	.25	11.70	81.15	14966	1.19
206	80–30–F	180	5.07	.23	13.23	81.47	14746	.99
209	160–20–F	180	5.97	.33	12.27	81.43	14636	1.53
220	160–26–P	180	4.83	.18	13.30	81.73	15076	.55
219	160–30–P	180	5.10	.25	12.53	82.14	14966	1.12
210	160–23–F	129	6.55	.15	10.80	82.50	14746	.79
208	80–40–F	180	4.83	.23	12.84	82.10	14636	1.03
213	160–40–P	180	4.90	.47	12.57	82.06	14746	2.09
212	160–26–F	180	4.37	.30	13.00	82.33	14966	1.29

The efficiency of the boiler dropped rapidly as the rate of evaporation increased, the range being between the limits of 71.34 per cent. and 41.81 per cent.

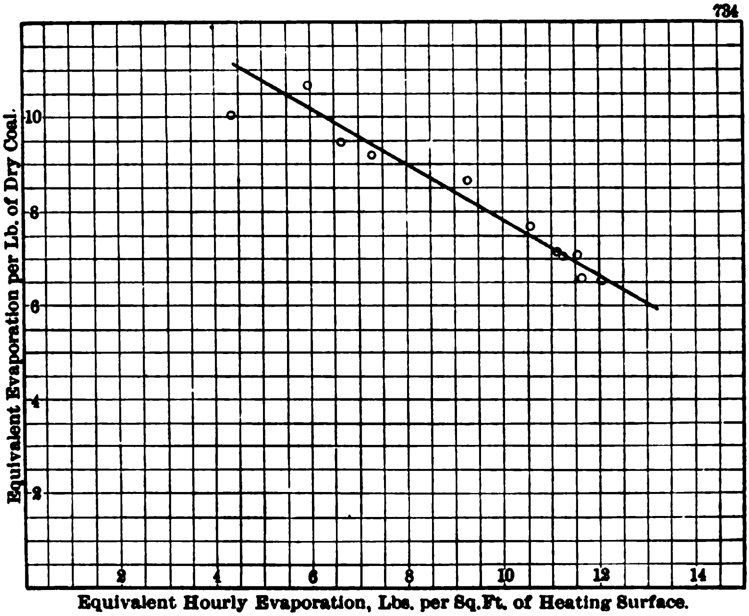


Fig. 205.— Rate of Evaporation and Evaporation per lb. of Coal.

From Fig. 205 the relation between H of equation (205) and E, the equivalent evaporation per pound of dry coal, is:

$$E = 13.7 - .587\,H \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (209)$$

SMOKE-BOX GASES—TABLE 208.

There was a tendency for the percentage of oxygen to decrease as the rate of evaporation increased—the range for the several tests being between the limits of 8.40 per cent. and 4.37 per cent.

The percentage of CO increased as the rate of evaporation increased, but not uniformly—the range for this locomotive being between the limits of 0.0 per cent. and .47 per cent.

The carbon dioxide, CO_2, ranged from 10.62 per cent. to 13.30 per cent.

PERFORMANCE OF ENGINES.

The arrangement of the results in Tables 209 and 210 has already been explained under this heading in Chapter XIII.

TABLE No. 209—GENERAL ENGINE CONDITIONS.

Identification of Test		Duration of Test. Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke H. P. Cylinder	Steam Pressure	
Test Number	Laboratory Designation					In Boiler Lbs. Per Sq. In.	In Branch-Pipe Lbs. Per Sq. In.
		Cal,	198	199	268 to 271	217	220
201	40-20-F	180	40.34	7.56	19.15	192.8	——
202	40-30-F	180	40.46	7.59	30.73	199.9	199.9
203	40-40-F	180	40.11	7.52	41.27	199.6	198.4
205	80-20-F	180	80.46	15.09	17.82	200.3	——
206	80-30-F	180	80.07	15.01	30.66	201.8	200.3
208	80-40-F	180	80.00	14.99	40.69	204.0	202.6
209	160-20-F	180	159.31	29.87	21.07	201.5	201.1
210	160-23-F	129	159.94	29.98	23.32	198.5	196.3
212	160-26-F	180	160.32	30.04	27.37	199.4	190.7
220	160-26-P	180	160.05	30.00	24.59	201.6	193.9
219	160-30-P	180	158.82	29.77	30.95	200.7	187.1
213	160-40-P	180	160.39	30.07	39.76	202.6	180.8

TABLE No. 210—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test		Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch	Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
Test Number	Laboratory Designation				
		Cal.	Cal.	379	381
201	40-20-F	180	71.66	299.4	29.56
202	40-30-F	180	103.80	434.4	27.78
203	40-40-F	180	132.65	550.4	27.31
205	80-20-F	180	63.34	527.0	25.89
206	80-30-F	180	94.51	782.6	24.55
208	80-40-F	180	116.32	962.5	24.93
209	160-20-F	180	52.57	865.6	25.11
210	160-23-F	129	57.67	953.7	24.67
212	160-26-F	180	61.55	1058.9	23.92
220	160-26-P	180	56.96	942.4	24.67
219	160-30-P	180	56.24	923.4	25.53
213	160-40-P	180	53.48	886.8	27.64

GENERAL ENGINE CONDITIONS—TABLE 209.

The lowest speed at which any test was run was 7.52 miles per hour, while the highest speed was 30.07 miles per hour. The critical speed (that speed at which reversal of stress on the dynamometer took place as described on page 109, Chapter IX, for this locomotive, as well as for locomotive No. 1499, was found to

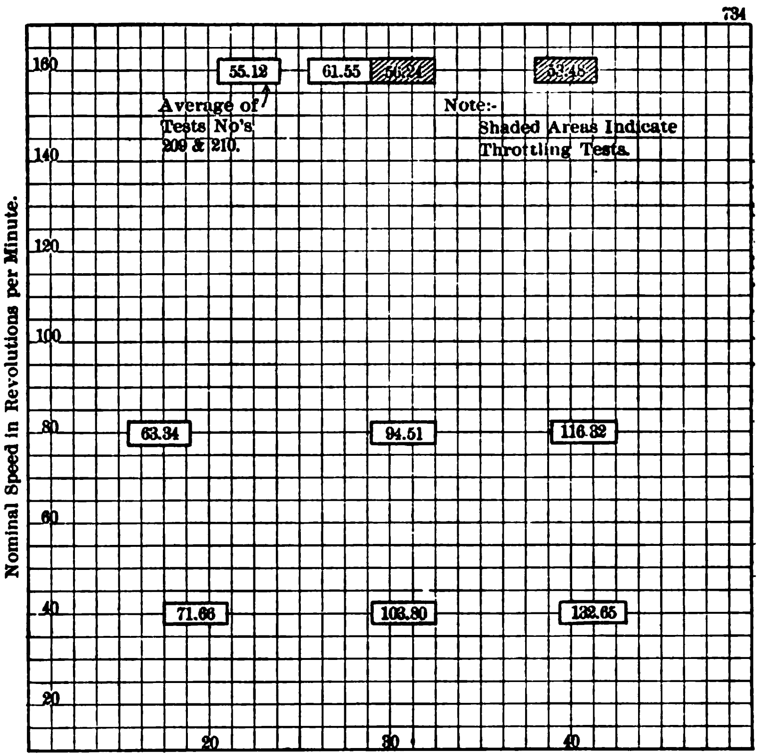


Fig. 206.— Mean Effective Pressure.

be 176 revolutions per minute, and higher speeds were not possible on this account. The safety bars were not fitted with dashpots when this locomotive was tested.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 210.

As in Chapter XIII the relation between the mean effective pressure, the indicated horse power and the steam consumption, respectively, for the several cut-offs and speeds is shown by Figs. 206, 207, and 208.

The best performance of the engine was at 27.37 per cent. cut-off and 160.32 revolutions per minute (about 30 miles per hour), under which conditions the steam consumption was 23.92 pounds per indicated horse power hour. At full throttle tests the steam per indicated horse power hour ranged from 23.92 to 29.56 pounds.

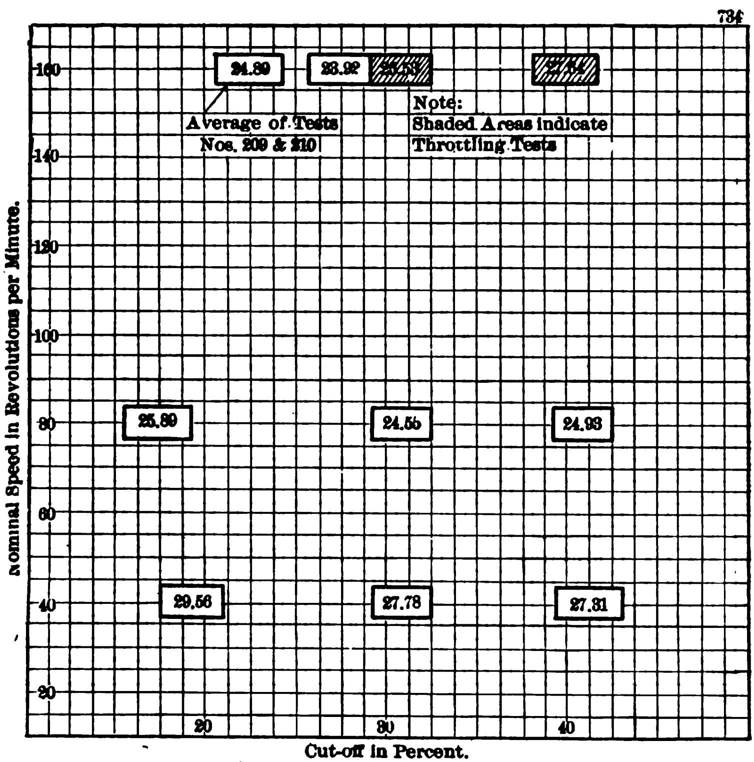


Fig. 207.— Dry Steam per I. H. P. Hour.

The highest indicated horse power was 1053.9, which was obtained at 27.37 per cent. cut-off and a speed of 160.32 revolutions per minute. Under these conditions of speed and cut-off, the steam consumption was the lowest obtained in any test, as noted above.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 211.

The maximum average recorded draw-bar pull was 24,522 pounds at a nominal speed of 40 revolutions per minute and a cut-

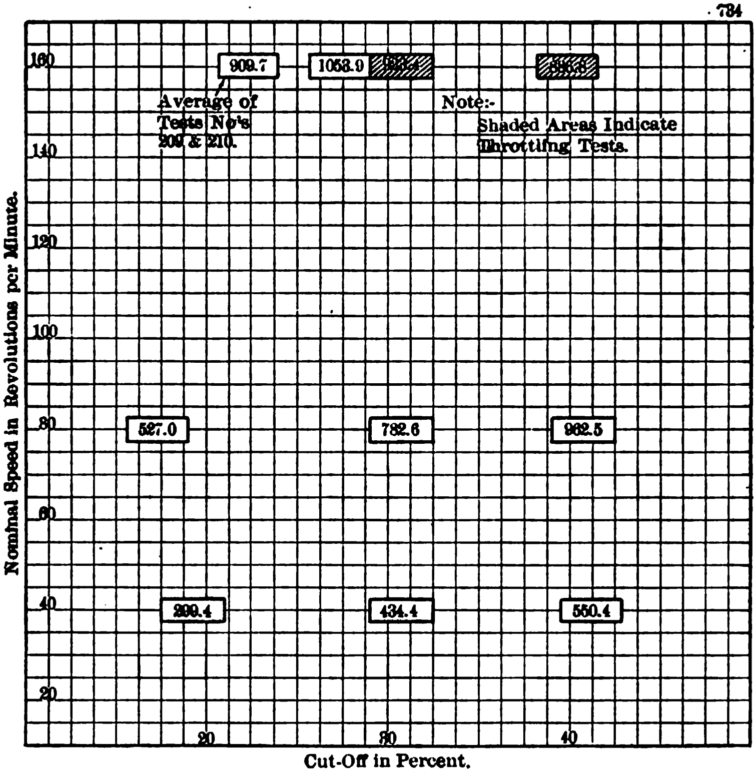


Fig. 208.— Total Indicated Horse Power.

off of 41.27 per cent. Higher draw-bar pulls were not obtained, because at slow speeds and long cut-offs there was constant danger of stalling the brakes and slipping the drivers owing to the fluctuations of the pressure of the water used for controlling the brakes.

The maximum dynamometer horse power was 896.8, which was obtained at a speed of 160.32 revolutions per minute and a cut-off of 27.37 per cent.

The minimum coal per dynamometer horse power hour obtained was 3.36 pounds and the maximum rate was 5.54 pounds per horse power hour.

TABLE No. 211—DYNAMOMETER RECORDS.

Identification of Test		Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D. H. P. Hour
Test Number	Laboratory Designation					
		Cal.	265	383	384	385
201	40–20–F	180	11531	232.5	4.55	33.07
202	40–30–F	180	19860	401.7	3.36	30.05
203	40–40–F	130	24522	491.8	3.98	30.57
205	80–20–F	180	11515	463.2	3.73	29.46
206	80–30–F	180	18288	732.0	3.65	26.26
208	80–40–F	180	22371	894.6	4.54	26.82
209	160–20–F	180	9861	785.3	4.25	27.69
210	160–23–F	129	10642	850.8	4.72	27.66
212	160–26–F	180	11188	896.8	5.16	28.12
220	160–26–P	180	10096	807.8	4.81	28.78
219	160–30–P	180	10546	837.4	4.78	28.15
213	160–40–P	180	9998	801.6	5.54	30.58

The lowest steam consumption per dynamometer horse power hour was 26.26 pounds, which was obtained at a speed of 80.07 revolutions per minute and a nominal cut-off of 30.66 per cent.

MACHINE FRICTION—TABLE 212.

As in Chapter XIII, the friction of the mechanism of the locomotive is given in terms of horse power, mean effective pressure and draw-bar pull.

The machine efficiency of this locomotive was very high, being in some cases over 90 per cent., while the machine efficiency of locomotive No. 1499 was never above 85 per cent. The difference is probably accounted for, in part, by the fact that No. 1499 was a new locomotive, while that of the L. S. & M. S. had been in service a long time and was, consequently, well worn; again, the No. 1499 was lubricated throughout with grease, both on rods and in driving box cellars, while No. 734 had grease cups on the rods and oil was used in the driving box cellars. It was felt that the grease caused more friction than the oil. To settle this point, arrangements were made with the L. S. & M. S. to send grease cellars for the locomotive. They were applied August 1, and on August 2 a series of tests of one hour each was started, which

TABLE No. 212—MACHINE FRICTION.

Identification of Test		Duration of Test, Minutes	Machine Friction in			Machine Efficiency Per Cent.
Test Number	Laboratory Designation		Horse Power	Mean Effective Pressure Lbs. Per Sq. in.	Draw-Bar Pull Pounds	
		Cal.	395	396	397	398
201	40-20-F	180	66.87	16.03	3316	77.66
202	40-30-F	180	32.69	7.81	1616	92.47
203	40-40-F	180	58.64	14.14	2924	89.35
	Average		**52.73**	**12.66**	**2619**	
205	80-20-F	180	63.78	7.67	1586	87.90
206	80-30-F	180	50.60	6.11	1264	93.53
208	80-40-F	180	67.90	8.21	1448	92.94
	Average		**60.76**	**7.33**	**1433**	
209	160-20-F	180	80.26	4.87	1008	90.78
210	160-23-F	129	102.88	6.22	1288	89.21
212	160-26-F	180	157.10	9.48	1961	85.09
220	160-26-P	180	134.64	8.14	1683	85.72
219	160-30-P	180	85.99	5.24	1083	90.69
218	160-40-P	180	85.22	5.14	1063	90.39
	Average		**107.68**	**6.52**	**1348**	

were repetitions of the tests already made when the locomotive had the ordinary oil and waste driving box cellars. Unfortunately, on the third test, when a draw-bar pull of 22,000 pounds was being exerted, the right front frame of the locomotive broke and it was impossible to continue the tests. The results, therefore, were not conclusive.

The machine efficiency of the locomotive ranged from 77.66 per cent. to 93.53 per cent.

MAXIMUM POWER OF LOCOMOTIVE.

It is impossible from the recorded data to construct directly for this locomotive a diagram showing the maximum draw-bar

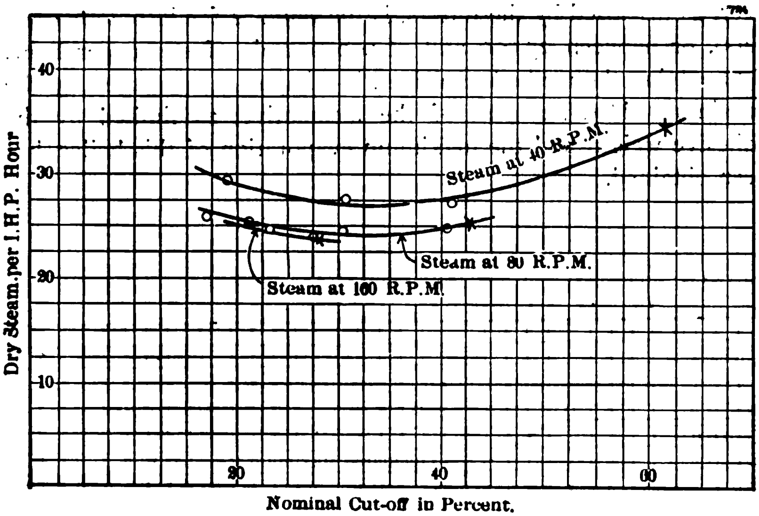


Fig. 209.— Steam Consumption.

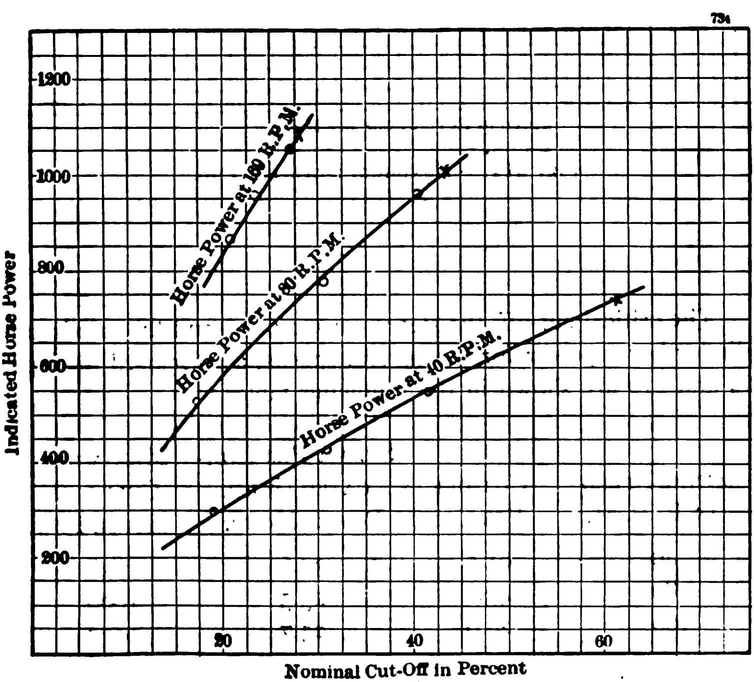


Fig. 210.— Indicated Horse Power.

pull at all speeds. The maximum evaporation for this boiler, however, as disclosed by these tests, is the same as for locomotive No. 1499, or between 25,000 and 26,000 pounds of steam per hour. By applying the method explained in Chapter XIII, page 143, the maximum draw-bar pull of the locomotive, as limited by the adhesive weight and the maximum evaporation of this boiler, has been obtained.

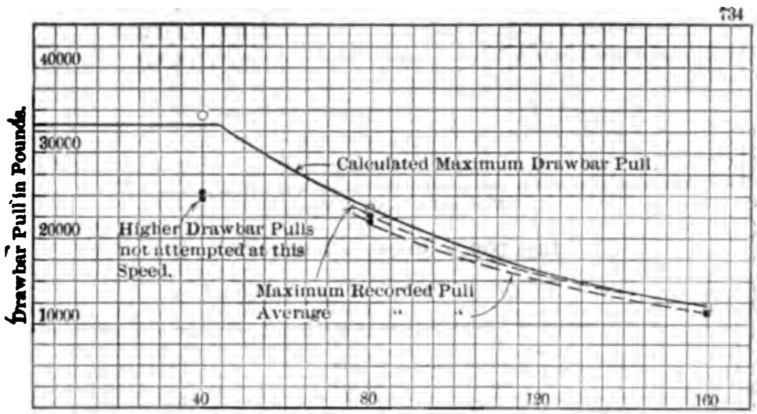


Fig. 211.— Maximum Draw-bar Pull.

The critical cut-off, the steam consumption and the maximum cylinder horse power for the several speeds, as disclosed by Figs. 209 and 210 are shown in the following table:

Nominal Speed in R. P. M.	Cut-off in Per Cent.	Steam per Indicated Horse Power Hour.	Maximum Cylinder Horse Power
40	61.5	34.6	738
80	43.0	25.5	1000
160	28.0	23.7	1075

The difference between the maximum cylinder horse power and the frictional horse power reduced to the equivalent draw-bar pull at the several speeds is given in the following table:

Speeds in R. P. M.	Maximum Estimated Draw-Bar Pull
40	34,281
80	23,567
160	12,102

The diagram, Fig. 211, shows that the lowest speed at which the full power of the boiler can be utilized is about 43 revolutions per minute. At 160 revolutions per minute the maximum recorded pull and the maximum calculated pull coincide.

APPENDIX 200.

The appendix contains:

1. Description, dimensions and proportions of the locomotive (pp. 217 to 222 inclusive.)

2. Summary of average results of tests. (pp. 223 to 233 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 234 to 242 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 243 to 257 inclusive.)

5. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 258 to 261 inclusive.)

6. A typical dynamometer diagram for each nominal speed. (pp. 262 and 263).

7. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of Lake Shore B Consolidation (2-8-0) Type Locomotive No. 734.

Built by the Brooks Locomotive Wks., Dunkirk, N. Y., 1900.

DRIVING WHEELS.

1	Number of pairs	4
2	Approximate diameter, inches	63

MEASURED CIRCUMFERENCE, FEET.

3	Right, No. 1	16.497
4	“ “ 2	16.510
5	“ “ 3	16.482
6	“ “ 4	16.488
7	“ “ 5	——
8	Left, “ 1	16.500
9	“ “ 2	16.496
10	“ “ 3	16.496
11	“ “ 4	16.502
12	“ “ 5	——
13	Average	16.496

ENGINE TRUCK WHEELS.

14	Number	2
15	Diameter, inches	36.68

TRAILING WHEELS.

16	Diameter, inches	——

WHEEL BASE, FEET.

17	Driving wheel base	17.342
18	Total wheel base	25.572
19	Gauge of wheels, in inches	56.00

WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.

20	On truck	18,700
21	“ 1st drivers	39,325
22	“ 2nd “	39,775
23	“ 3rd “	40,275
24	“ 4th “	43,225
25	“ 5th “	——
26	“ trailers	——
27	Total	181,300
28	“ on drivers	162,600

CYLINDERS.

29	High pressure, number	2
30	Low “ “	——
31	Arrangement	Outside

DIAMETER, INCHES.

32 High pressure, right 21.004
33 “ “ left 21.023
34 Low “ right .... ——
35 “ “ left .... ——

STROKE OF PISTON, FEET.

36 High pressure, right 2.499
37 “ “ left 2.500
38 Low “ right .... ——
39 “ “ left .... ——

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40 H. P., right, head end 9.21
41 “ “ crank “ 9.21
42 “ left, head “ 9.26
43 “ “ crank “ 9.36
44 L. P., right, head “ .... ——
45 “ “ crank “ .... ——
46 “ left, head “ .... ——
47 “ “ crank “ .... ——

RECEIVER, CUBIC FEET.

48 Volume, right side .... ——
49 “ left “ .... ——

STEAM PORTS, INCHES.

(For piston valves the length equals the circumference of inside of bushing, minus the sum of the widths of bridges.)

50 H. P. admission, right, head end, length 18.84
51 “ “ “ “ “ width 1.656
52 “ “ “ crank “ length 18.84
53 “ “ “ “ “ width 1.625
54 “ “ left, head “ length 18.92
55 “ “ “ “ “ width 1.625
56 “ “ “ crank “ length 18.92
57 “ “ “ “ “ width 1.625
58 L. P. “ right, head “ length .... ——
59 “ “ “ “ “ width .... ——
60 “ “ “ crank “ length .... ——
61 “ “ “ “ “ width .... ——
62 “ “ left, head “ length .... ——
63 “ “ “ “ “ width .... ——
64 “ “ “ crank “ length .... ——
65 “ “ “ “ “ width .... ——
66 H. P. exhaust, right, length 18.86
67 “ “ “ width 2.734
68 “ “ left, length 18.94
69 “ “ “ width 2.75
70 L. P. “ right, length .... ——

71	L. P. exhaust, right, width	——
72	“ “ left, length	——
73	“ “ “ width	——

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	3.737
75	“ “ left	3.733
76	Low “ right	——
77	“ “ left	——

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	“ “ left	——
80	Low “ right	——
81	“ “ left	——

VALVES.

82	Type	“D” slide
83	Design	Allen–Richardson
84	Per cent. of balanced to total area	R. S. 52.99 L. S. 53.13
85	Type of link motion	Stephenson, open rods

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	5.63
87	“ “ left	5.65
88	Low “ right	——
89	“ “ left	——

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure right, head end	.992
91	“ “ “ crank “	.992
92	“ “ left, head “	1.078
93	“ “ “ crank “	1.078
94	Low “ right, head “	——
95	“ “ “ crank “	——
96	“ “ left, head “	——
97	“ “ “ crank “	——

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	negative	.016
99	“ “ “ crank “	“	.016
100	“ “ left, head “	“	.078
101	“ “ “ crank “	“	.078
102	Low “ right, head “		——
103	“ “ “ crank “		——
104	“ “ left, head “		——
105	“ “ “ crank “		——

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	No. 16 U. S. G. sheet iron
108	Lead, forward motion, inches	.141 negative
109	....	
110	....	
111	....	
112	Right crank leads.	

BOILER.

113	Type	Extended wagon top, radial stays
114	Outside diameter, 1st ring, inches	68.375

TUBES.

115	Number	338.
116	Outside diameter, inches	2.
117	Thickness, inches	.120
118	Length between tube sheets, inches	178.937
119	Total fire area, square feet	5.71
120	Serve tubes, number of ribs	——
121	" " sq. in, of inside surface in one in. of length	——
122	....	
123	....	
124	Boiler pressure, pounds per sq. in.	200

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129	....	
130	....	
131	....	

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	119.38
133	Width	40.86
134	Depth, front end	75.42
135	" back "	61.68
136	Volume, cubic feet (less arch and tubes)	218.00
137	Air inlets to ash pan (no dampers) sq. ft.	4.88
138	....	
139	....	
140	....	

FIRE DOORS.

141	Number	one
142	Area square feet	1.36
143		

GRATES.

144	Style	rocking
145	Total area, square feet	33.76
146	" " dead grates, square feet	0.
147	Width of air spaces, inches	.69

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	0.
149	" grates	11.39
150	" fire doors	.06
151	Total air inlets (148) (149) and (150)	11.45
152	Ratio " " (149) to grate area (145)	.337
153	" " " (151) " " " (145)	.339

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	2638.97
155	" " " fire "	2322.30
156	" " firebox, fire side, including arch tubes	218.92
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	2541.22
159	Total, based on inside of firebox and outside of tubes	2857.89

BOILER VOLUMES.

(With water surface at level of second gauge cock.)

160	Water space, cubic feet	341.82
161	Steam " " "	79.91

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	5.245
164	" " left, "	
165	Area of right, square inches	——
166	" " left, " "	——
167	Total area, square inches	21.60

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	41
169	L. P. " " " " "	—
170		

RATIOS.

171	Heating surface (158) to grate area (145)	75.27
172	Fire area through tubes (119) to grate area (145)	.169
173	Firebox heating surface (156) to grate area (145)	6.48
174	Tube surface (155) to firebox heating surface (156)	10.61
175	Firebox volume (136) to grate area (145)	6.458
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(power developed at one R. P. M. when pull is one pound.)

179	....	.0004999

CONSTANTS FOR INDICATED HORSE POWER

(power developed at one R. P. M. and one pound M. E. P.)

180	High	pressure	cylinder,	right,	head	end	....	.02624
181	"	"	"	"	crank	"	....	.02541
182	"	"	"	left,	head	"	....	.02629
183	"	"	"	"	crank	"	....	.02546
184	Low	"	"	right,	head	"	....	——
185	"	"	"	"	crank	"	....	——
186	"	"	"	left,	head	"	....	——
187	"	"	"	"	crank	"	....	——

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head	end	....	6.013
189	"	"	"	"	crank	"	....	5.823
190	"	"	"	left,	head	"	....	6.025
191	"	"	"	"	crank	"	....	5.834
192	Low	"	"	right,	head	"	....	——
193	"	"	"	"	crank	"	....	——
194	"	"	"	left,	head	"	....	——
195	"	"	"	"	crank	"	....	——

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734, LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed: Revolutions: Total	Speed: Revolutions: Average Per Minute	Speed: Equivalent: Speed in Miles Per Hour	Speed: Equivalent: Piston Speed in Feet Per Minute	Position of Levers: Reverse, Notches From Front End	Position of Levers: Tests marked thus * not plotted	Position of Levers: Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	
		196	197	198	199	200	201	202	203	204	205
201	40-20-F	3.00	7262	40.34	7.56	201.7	36		FULL	52	
202	40-30-F	3.00	7283	40.46	7.59	202.3	32		FULL	64	
203	40-40-F	2.166	5215	40.11	7.52	200.5	29		FULL	70	
204	80-45-F	2.366	11198	79.99	14.99	399.9	28	*	FULL	68	
205	80-20-F	3.00	14482	80.46	15.09	402.2	36		FULL	54	
206	80-30-F	3.00	14413	80.07	15.01	400.3	32		FULL	62	
208	80-40-F	3.00	14401	80.00	14.99	399.9	29		FULL	94	
209	160-20-F	3.00	28676	159.31	29.87	796.4	36		FULL	92	
210	160-23-F	2.15	20632	159.94	29.98	799.6	35		FULL	76	
211	160-27-F	1.166	11201	160.01	30.00	799.9	33	*	FULL	71	
212	160-26-F	3.00	28858	160.32	30.04	801.0	34		FULL	74	
213	160-40-P	3.00	28871	160.39	30.07	801.8	29		1.00	64	
214	40-20-F	1.00	2375	39.58	7.42	197.9	36		FULL		
215	80-20-F	1.00	4802	80.13	15.02	400.6	36		FULL		
216	80-40-F	1.00	4372	79.49	14.90	397.4	29		FULL		
217	160-40-P	1.00	9713	159.23	29.85	796.0	29	*	1.60	53	
218	160-40-P	2.075	19933	160.10	30.01	800.4	29	*	1.25	61	
219	160-30-P	3.00	28587	158.82	29.77	793.9	32		1.25	77	
220	160-26-P	3.00	28809	160.05	30.00	800.1	35		2.00	68	
221	120-35-F	.50	3568	118.90	22.28	594.4	31		FULL		
222	120-40-F	.50	3581	119.37	22.38	596.8	30		FULL		

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of: Smoke Box: By Thermometer	Smoke Box: By Pyrometer	Laboratory: Dry Bulb	Laboratory: Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer				Steam lost from Boiler, etc. Lbs. per hour
		206	207	208	209	210	211	212	213	214	215	216
201	40-20-F	517	513	68.7	58.4	——	73.8	1885				439
202	40-30-F	549	530	80.7	72.0	387.6	72.8	1924				576
203	40-40-F	578	551	74.3	65.5	387.0	76.0	1992				539
204	80-45-F	673	646	81.9	71.7	377.4	76.6	1999				366
205	80-20-F	573	573	71.8	61.0	——	73.7	2000				426
206	80-30-F	624	607	76.0	71.4	387.6	73.0	1938				448
208	80-40-F	672	650	78.9	71.7	388.7	72.8	2152				553
209	160-20-F	642	628	83.5	74.8	382.9	73.6	1945				598
210	160-23-F	668	651	75.4	68.4	386.1	74.7	2203				444
211	160-27-F	659	659	79.8	74.2	377.3	75.9	2014				366
212	160-26-F	671	667	80.2	65.7	383.9	76.4	2162				401
213	160-40-P	680	669	75.6	70.1	355.8	76.4	2220				355
214	40-20-F	TESTS WITH GREASE CELLARS IN DRIVING BOXES										
215	80-20-F	"	"	"	"	"	"	"				
216	80-40-F	"	"	"	"	"	"	"				
217	160-40-P	648	632	85.1	75.2	371.7	75.5	2013				326
218	160-40-P	683	659	83.7	74.5	343.9	77.2	2240				335
219	160-30-P	667	654	77.6	64.3	359.1	77.3	2221				458
220	160-26-P	663	640	74.6	68.3	385.0	76.3	2312				406
221	120-35-F	PULL SPEED TEST										
222	120-40-F	"	"	"								

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.

Lake Shore and Michigan Southern Railway Company.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	In Boiler: Maximum	In Boiler: Minimum	In Branch Pipe	Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box: Front of Diaphragm	In Smoke Box: Back of Diaphragm	In Fire Box	In Ash Pan	Injectors: Hours in Action: Total, Right	Total, Left
		217	218	219	220	221	222	223	224	225	226	227
201	40–20–F	192.3	205.0	166.0	——	14.605	1.38	.19	——	.25	1.06	0
202	40–30–F	199.9	206.0	189.0	199.9	14.474	2.38	.93	.70	.42	1.58	0
203	40–40–F	199.6	204.4	193.9	198.4	14.513	3.06	1.36	.35	.10	1.583	0
204	80–45–F	178.0	200.4	150.0	175.5	14.468	5.70	2.65	.78	.16	2.216	0
205	80–20–F	200.3	203.0	196.0	——	14.606	2.90	.62	——	.22	1.70	0
206	80–30–F	201.8	209.5	195.5	200.3	14.466	4.15	2.12	1.12	.20	3.54	0
208	80–40–F	204.0	209.5	194.5	202.6	14.462	5.85	2.84	1.26	.20	3.90	0
209	160–20–F	201.5	209.0	183.0	201.1	14.449	4.89	2.31	1.20	.15	3.93	.01
210	160–23–F	198.5	209.1	187.0	196.3	14.405	5.33	2.79	1.21	.23	3.13	0
211	160–27–F	178.4	205.1	156.9	175.3	14.402	5.73	3.03	1.51	.25	1.104	.0011
212	160–26–F	199.4	207.4	188.0	190.7	14.543	5.91	3.21	.97	.15	2.993	0
213	160–40–P	202.6	206.9	196.4	130.8	14.485	5.85	2.98	1.08	.16	2.95	0
214	40–20–F	198.4										
215	80–20–F	199.5										
216	80–40–F	198.7										
217	160–40–P	199.3	207.4	192.5	117.8	14.479	5.25	3.08	1.08	.14	1.016	0
218	160–40–P	200.8	207.4	194.5	124.7	14.520	5.47	3.01	1.29	.19	2.022	0
219	160–30–P	200.7	207.4	191.0	187.1	14.551	5.02	2.73	1.12	.15	2.990	0
220	160–26–P	201.6	205.9	195.5	193.9	14.509	5.35	2.68	.80	.18	2.975	0
221	120–35–F	189.4					6.40	3.20				
222	120–40–F	187.9					7.50	3.40				

Test Number	Laboratory Designation	Quality of steam: In Dome	In Branch Pipe	Degrees of Superheat in Branch Pipe	Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Coal Fired: Kind	Coal Fired: Total	Coal Fired: Per Cent of Moisture	Total: Dry Coal Fired	Total: Combustible by Analysis	Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
201	40–20–F	.9860	——	——	.98980	Bituminous	3352	.73	3328	3128	200
202	40–30–F	.9871	.9915	0	.99064		4271	.83	4236	3949	286
203	40–40–F	.9856	.9919	0	.98954	"	4439	1.10	4389	4104	285
204	80–45–F	.9880	.9964	0	.99120	"	10709	1.29	10571	9776	795
205	80–20–F	.9849	——	——	.98802	"	5387	.80	5344	4968	376
206	80–30–F	.9865	.9978	0	.99020	"	8285	1.16	8188	7720	469
208	80–40–F	.9837	.9949	0	.98823	"	12599	1.13	12456	11638	830
209	160–20–F	.9871	.9928	0	.99060	"	10416	1.08	10304	9691	615
210	160–23–F	.9868	.9959	0	.99040	"	8897	1.00	8808	8314	494
211	160–27–F	.9873	.9971	0	.99060	"	5954	.89	5901	5481	420
212	160–26–F	.9856	.9964	0	.98953	"	14179	.67	14084	13202	882
213	160–40–P	.9855	1.0082	14.74	.98947	"	13686	1.24	13515	12657	858
214	40–20–F										
215	80–20–F										
216	80–40–F										
217	160–40–P	.9871	1.0130	23.53	.99060	"	4013	.94	3975	3699	276
218	160–40–P	.9854	1.0099	17.85	.98930	"	9445	.95	9355	8772	883
219	160–30–P	.9855	1.0053	9.50	.98970	"	12343	.85	12238	11559	679
220	160–26–P	.9861	.9954	0	.98970	"	11938	.73	11851	11190	661
221	120–35–F										
222	120–40–F										

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.
LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs. Total: Cinders Collected in Smoke Box	Sparks Discharged From Stack	Cinders and Sparks	Analysis of Coal, Per Cent: Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
201	40-20-F	0	150	150	77.01	16.31	.73	5.95	.97		
202	40-30-F	90	275	365	75.93	16.54	.83	6.70	1.27		
203	40-40-F	73	281	354	75.72	16.75	1.10	6.43	.86		
204	80-45-F	51	1000	1051	74.34	16.95	1.29	7.42	.95		
205	80-20-F	0	149	149	76.00	16.22	.80	6.98	1.02		
206	80-30-F	45	719	764	76.56	16.62	1.16	5.66	.81		
208	80-40-F	39	1003	1042	75.57	16.71	1.13	6.59	1.18		
209	160-20-F	53	901	954	76.41	16.61	1.08	5.90	.79		
210	160-23-F	55	864	919	76.82	16.63	1.00	5.55	.93		
211	160-27-F	106	803	909	75.20	16.86	.89	7.05	.85		
212	160-26-F	53	1060	1113	76.29	16.82	.67	6.22	.67		
213	160-40-P	103	1019	1122	76.16	16.33	1.24	6.27	.79		
214	40-20-F										
215	80-20-F										
216	80-40-F										
217	160-40-P	75	530	605	75.68	16.51	.94	6.87	1.10		
218	160-40-P	69	956	1025	76.03	16.85	.95	6.17	.83		
219	160-30-P	59	980	1039	76.92	16.73	.85	5.50	.66		
220	160-26-P	49	985	1034	76.98	16.75	.73	5.54	.92		
221	120-35-F										
222	120-40-F										

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B. T. U.: Of Dry Coal	Of Combustible	Of Cinders	Of Sparks		Analysis of Smoke Box Gases, Per Cent: Oxygen O	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
201	40-20-F	14854	15801	10124	9244		8.40	.07	10.62	80.91		
202	40-30-F	14537	15589	11004	8143		7.60	.00	11.07	81.33		
203	40-40-F	15132	16076	11884	11664		6.90	.25	11.70	81.15		
204	80-45-F	14827	16032	12104	11884		4.10	.27	13.87	82.26		
205	80-20-F	14865	15990	——	9684		7.97	.00	10.73	81.30		
206	80-30-F	14818	15825	12105	11884		5.07	.23	13.23	81.47		
208	80-40-F	14803	15860	12325	11775		4.83	.23	12.84	82.10		
209	160-20-F	14795	15734	11774	11665		5.97	.33	12.27	81.43		
210	160-23-F	14794	15779	12325	11884		6.55	.15	10.80	82.50		
211	160-27-F	14878	16001	11884	11665		5.00	.20	12.70	82.10		
212	160-26-F	15067	16073	12104	12104		4.37	.30	13.00	82.33		
213	160-40-P	14943	15944	12325	11884		4.90	.47	12.57	82.06		
214	40-20-F											
215	80-20-F											
216	80-40-F											
217	160-40-P	14668	15756	11445	11224		5.30	.20	12.20	82.30		
218	160-40-P	14776	15757	12104	11225		5.40	.15	12.25	82.20		
219	160-30-P	15094	15981	12325	11885		5.10	.23	12.53	82.14		
220	160-26-P	15187	16084	12325	12104		4.83	.13	13.30	81.73		
221	120-35-F											

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.
LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

Test Number	Laboratory Designation	Water, in Pounds						Dynamometer		
		Delivered to Injectors	Lost				Delivered to Boiler and Presumably Evaporated	Drawbar Pull in Pounds		
			From Boiler	From Injectors	From	Total		Average	Maximum	Minimum
		259	260	261	262	263	264	265	266	267
201	40-20-F	28144	0	0		0	28144	11531	12200	9478
202	40-30-F	39095	0	821		821	38274	19860	21468	17450
203	40-40-F	36843	306	2500		2806	34037	24522	25301	24000
204	80-45-F	57157	0	142		142	57015	20444	23163	17224
205	80-20-F	42709	0	0		0	42709	11515	11786	11210
206	80-30-F	60138	0	558		558	59580	18288	19006	17925
208	80-40-F	74678	0	170		170	74508	22871	22929	21667
209	160-20-F	67958	0	549		549	67638	9861	10904	9006
210	160-23-F	52134	0	85		85	52049	10642	11234	10095
211	160-27-F	31054	0	138		138	30916	10755	11788	9603
212	160-26-F	77693	0	47		47	77646	11188	12000	10382
213	160-40-P	75506	0	130		130	75376	9998	10807	9602
214	40-20-F							12725	14428	11044
215	80-20-F							11847	12450	11189
216	80-40-F							22001	22355	21468
217	160-40-P	24636	0	10		10	24626	9540	9655	9255
218	160-40-P	51671	0	150		150	51521	10538	11070	9903
219	160-30-P	72939	0	98		98	72841	10546	11091	10098
220	160-26-P	72236	0	555		555	71681	10096	10619	9251
221	120-35-F							16104	16953	15307
222	120-40-F							16744	17975	14955

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Cut-off, Per Cent. of Stroke								Release, Per Cent. of Stroke			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
201	40-20-F	20.8	19.6	18.6	17.6					58.3	59.2	59.4	60.7
202	40-30-F	33.1	30.0	31.4	28.4					70.8	72.0	70.4	70.9
203	40-40-F	44.8	39.8	40.7	39.7					78.7	78.2	77.7	74.5
204	80-45-F	48.3	42.2	43.6	41.5					78.1	78.2	78.7	77.7
205	80-20-F	18.3	16.6	18.6	15.8					60.7	60.1	57.8	59.4
206	80-30-F	32.1	29.0	32.7	28.9					69.5	68.3	68.2	67.9
208	80-40-F	45.1	38.5	41.1	38.2					75.7	74.9	76.5	75.8
209	160-20-F	22.9	20.4	20.9	20.1					57.1	57.9	59.6	58.5
210	160-23-F	24.8	22.7	23.6	22.3					62.2	62.4	61.4	62.8
211	160-27-F	30.7	30.4	27.8	27.1					68.5	66.6	64.9	64.8
212	160-26-F	30.0	27.3	25.5	26.8					64.6	64.2	65.2	62.9
213	160-40-P	41.2	40.5	40.2	37.2					76.7	75.7	74.8	76.0
214	40-20-F	20.8	19.6	19.3	17.8					61.3	61.7	61.9	61.5
215	80-20-F	21.6	18.6	19.1	19.4					63.0	61.5	63.6	63.5
216	80-40-F	45.2	37.3	40.5	37.5					77.7	76.5	77.6	76.0
217	160-40-P	41.4	39.1	36.9	36.7					73.6	73.4	71.7	68.7
218	160-40-P	40.5	39.2	39.2	37.2					75.4	73.0	73.5	70.8
219	160-30-P	31.7	31.5	30.1	30.5					63.2	65.3	63.7	63.5
220	160-26-P	28.6	24.9	22.2	22.8					62.8	62.7	62.6	62.3
221	120-35-F	38.3	35.3	34.8	34.4					73.4	71.8	71.0	71.4
222	120-40-F	39.9	38.0	36.5	35.6					74.8	73.8	73.0	74.6

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734, LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
201	40-20-F					38.1	38.1	38.3	39.8				
202	40-30-F					30.0	27.0	26.8	28.1				
203	40-40-F					24.0	20.2	23.2	24.5				
204	80-45-F					25.4	22.4	25.2	26.3				
205	80-20-F					40.6	39.2	43.2	41.4				
206	80-30-F					29.0	27.8	27.4	27.2				
208	80-40-F					24.1	22.6	25.3	23.3				
209	160-20-F					41.7	41.2	40.3	41.8				
210	160-23-F					39.4	39.6	38.6	40.6				
211	160-27-F					37.7	34.9	38.4	36.6				
212	160-26-F					38.4	35.3	37.6	37.4				
213	160-40-P					33.5	30.1	33.8	32.1				
214	40-20-F					38.8	38.6	38.8	39.7				
215	80-20-F					42.7	37.3	39.3	40.1				
216	80-40-F					27.1	22.9	26.7	26.4				
217	160-40-P					31.4	29.4	33.1	33.9				
218	160-40-P					32.6	30.5	33.3	33.3				
219	160-30-P					35.2	34.2	36.3	34.3				
220	160-26-P					40.0	38.6	38.8	37.3				
221	120-35-F					28.4	27.0	28.8	30.4				
222	120-40-F					32.6	29.9	32.3	34.0				

Test Number	Laboratory Designation	Pressure from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
201	40-20-F	198.7	198.1	196.7	195.4					1.1978
202	40-30-F	201.3	202.1	190.2	189.5					1.1996
203	40-40-F	206.9	204.5	205.7	202.3					1.1960
204	80-45-F	187.6	185.1	186.3	183.6					1.1932
205	80-20-F	195.8	198.6	188.9	191.4					1.1987
206	80-30-F	194.7	195.4	188.3	187.5					1.1995
208	80-40-F	198.2	198.6	193.9	193.3					1.2000
209	160-20-F	182.5	192.8	183.6	185.3					1.1990
210	160-23-F	210.2	205.6	200.3	196.8					1.1975
211	160-27-F	185.8	179.1	191.0	180.0					1.1940
212	160-26-F	215.3	214.3	212.6	205.7					1.1956
213	160-40-P	124.4	125.1	123.7	122.8					1.1950
214	40-20-F	205.1	205.2	204.6	186.6					
215	80-20-F	207.9	179.3	208.0	201.9					
216	80-40-F	210.1	196.8	210.0	204.1					
217	160-40-P	112.5	117.3	114.1	110.0					1.1965
218	160-40-P	128.0	123.5	122.7	117.2					1.1948
219	160-30-P	161.1	158.1	157.1	155.1					1.1948
220	160-26-P	207.2	202.2	206.8	200.8					1.1959
221	120-35-F	195.0	194.8	202.1	194.0					

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.
Lake Shore and Michigan Southern Railway Company.

Test Number	Laboratory Designation	Pressures from Indicator Cards								
		Steam Chest Pressures, Pounds Per Square Inch					Pressures at Cut-off, Pounds Per Square Inch			
		High Pressure		Low Pressure			High Pressure Cylinder			
							Right Side		Left Side	
		Right Side	Left Side	Right Side	Left Side		Head End	Crank End	Head End	Crank End
		301	302	303	304	305	306	307	308	309
201	40–20–F	200.6	199.0				186.7	180.1	183.1	180.0
202	40–30–F	204.3	193.0				184.1	189.7	166.5	172.7
203	40–40–F	203.8	202.3				185.4	188.8	185.6	184.3
204	80–45–F	176.9	172.5				153.0	150.6	148.2	149.6
205	80–20–F	198.7	193.9				178.2	185.9	160.0	174.4
206	80–30–F	198.5	192.5				165.2	168.4	149.6	158.3
208	80–40–F	203.1	199.1				161.2	170.2	162.7	163.2
209	160–20–F	198.4	189.4				143.4	151.0	143.4	154.5
210	160–23–F	195.4	188.9				143.3	146.3	136.2	142.3
211	160–27–F	178.6	172.4				185.8	125.6	191.0	128.2
212	160–26–F	206.8	205.7				135.3	137.1	143.1	139.5
213	160–40–P	123.2	122.4				90.3	91.8	88.5	91.0
214	40–20–F	204.6	204.4				189.3	184.8	185.7	186.6
215	80–20–F	201.9	200.0				179.3	179.3	174.9	171.2
216	80–40–F	199.2	198.2				170.9	176.5	171.3	171.8
217	160–40–P	114.3	114.1				80.6	87.5	84.7	84.6
218	160–40–P	115.5	121.3				87.8	90.2	87.6	76.5
219	160–30–P	160.6	158.1				116.1	116.7	118.4	115.6
220	160–26–P	197.8	196.3				132.2	137.8	148.4	141.7
221	120–35–F	190.9	204.8				142.0	147.9	153.0	145.4
222	120–40–F	179.7	182.7				145.4	139.8	142.2	145.1

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Cut-off, Pounds Per Square Inch				Pressures at Release, Pounds Per Square Inch							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
201	40–20–F					72.0	63.7	63.8	59.4				
202	40–30–F					85.4	79.3	75.9	69.7				
203	40–40–F					101.7	94.3	95.3	90.2				
204	80–45–F					89.5	77.8	77.3	76.6				
205	80–20–F					60.5	58.2	56.0	52.3				
206	80–30–F					77.3	72.8	72.2	67.6				
208	80–40–F					94.7	84.8	92.4	81.6				
209	160–20–F					61.2	56.6	53.9	58.8				
210	160–23–F					58.0	54.4	55.4	55.4				
211	160–27–F					54.5	56.1	56.0	54.0				
212	160–26–F					61.9	59.1	54.5	58.3				
213	160–40–P					44.5	46.5	43.5	43.5				
214	40–20–F					71.4	64.5	62.8	60.3				
215	80–20–F					65.2	57.7	55.8	54.8				
216	80–40–F					92.8	85.3	87.5	82.7				
217	160–40–P					42.4	45.8	43.0	42.7				
218	160–40–P					44.2	46.0	46.5	45.1				
219	160–30–P					56.9	53.2	54.4	53.6				
220	160–26–P					59.3	55.0	52.1	54.5				
221	120–35–F					72.2	72.1	74.7	68.3				

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.
Lake Shore and Michigan Southern Railway Company.

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Beginning of Compression, Pounds Per Square Inch								Least Back Pressure, Pounds Per Square Inch			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
201	40-20-F	8.1	4.8	4.6	3.9					4.6	.7	1.7	.7
202	40-30-F	4.0	3.0	4.7	5.4					1.5	3.5	1.6	1.6
203	40-40-F	3.3	3.8	4.6	4.2					.0	1.6	1.0	.0
204	80-45-F	10.5	9.5	10.7	12.3					3.5	3.2	3.4	3.5
205	80-20-F	6.8	9.4	6.9	7.7					3.7	5.5	3.7	4.2
206	80-30-F	11.7	12.0	13.1	13.3					2.4	2.7	3.1	2.8
208	80-40-F	12.5	13.0	14.8	16.3					4.3	4.3	5.4	4.3
209	160-20-F	17.8	14.9	16.2	17.1					5.9	4.3	5.4	5.5
210	160-23-F	17.2	16.0	17.5	19.0					6.5	4.8	5.2	7.5
211	160-27-F	17.4	17.8	17.0	19.2					7.3	7.2	5.6	7.1
212	160-26-F	18.5	19.8	20.6	20.9					7.3	7.2	6.5	8.4
213	160-40-P	14.6	15.5	15.4	16.4					6.1	6.0	5.9	6.7
214	40-20-F	2.6	3.4	4.4	3.8					.0	1.0	1.7	.6
215	80-20-F	5.7	8.2	8.3	9.1					1.5	2.2	2.2	1.6
216	80-40-F	10.3	10.6	12.1	14.0					4.2	3.5	4.0	3.3
217	160-40-P	13.8	17.4	14.4	14.0					6.1	11.3	5.7	5.2
218	160-40-P	14.7	15.2	17.8	14.0					5.7	6.4	7.8	6.7
219	160-30-P	16.8	16.7	19.1	18.4					5.4	5.7	6.5	6.6
220	160-26-P	16.6	16.9	18.9	20.4					5.4	5.1	5.9	9.5
221	120-35-F	17.0	18.5	22.0	18.1					6.3	7.2	7.7	7.4
222	120-40-F	14.8	16.1	18.1	17.6					7.6	6.4	7.7	8.1

Test Number	Laboratory Designation	Pressures from Indicator Cards				Boiler					
		Least Back Pressure, Pounds Per Square Inch				Dry Coal Fired Pounds		Evaporation, Pounds			
		Low Pressure Cylinder						Steam Per Hour			
		Right Side		Left Side							
		Head End	Crank End	Head End	Crank End	Per Hour	Per Hour Per Square Foot of Grate Surface	Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
201	40-20-F					1109	32.85	9381	9285	3.654	8.372
202	40-30-F					1412	41.82	12758	12638	4.974	8.950
203	40-40-F					2027	60.03	15713	15549	6.119	7.674
204	80-45-F					4468	132.33	24098	23886	9.399	5.346
205	80-20-F					1781	52.75	14236	14065	5.535	7.897
206	80-30-F					2729	80.83	19860	19665	7.739	7.206
208	80-40-F					4152	122.97	24836	24544	9.658	5.912
209	160-20-F					3435	101.73	22546	22335	8.789	6.527
210	160-23-F					4096	121.33	24207	23975	9.435	5.853
211	160-27-F					5061	149.90	26515	26265	10.335	5.190
212	160-26-F					4695	139.04	25882	25610	10.077	5.455
213	160-40-P					4505	133.43	25125	24860	9.783	5.519
214	40-20-F										
215	80-20-F										
216	80-40-F										
217	160-40-P					3975	117.73	24626	24394	9.600	6.137
218	160-40-P					4509	133.50	24830	24564	9.668	5.449
219	160-30-P					4079	120.83	24280	24030	9.450	5.987
220	160-26-P					3950	117.03	23893	23646	9.304	5.986
221	120-35-F										
222	120-40-F										

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 784.

Lake Shore and Michigan Southern Railway Company.

Test Number	Laboratory Designation	Boiler							Engines			
		Equiv't Evap'n from and at 212° F., Pounds					Boiler Horse Power	Efficiency of Boiler	Mean Effective Pressure, Pounds Per Square Inch			
				Per Pound of					High Pressure Cylinder			
									Right Side		Left Side	
		Per Hour	Per Hour, Per Sq. Ft. of Heat. Surface	Coal as Fired	Dry Coal as Fired	Combustible			Head End	Crank End	Head End	Crank End
		344	345	346	347	348	349	350	351	352	353	354
201	40–20–F	11122	4.88	9.96	10.03	10.66	322.4	65.20	72.98	72.20	71.87	69.59
202	40–30–F	15162	5.97	10.65	10.74	11.52	439.5	71.34	107.53	100.13	105.76	101.78
203	40–40–F	18599	7.32	9.08	9.18	9.82	539.1	58.57	138.08	134.19	131.70	126.64
204	80–45–F	28500	11.21	6.38	6.35	6.89	826.1	41.53	114.16	109.67	108.05	108.77
205	80–20–F	16864	6.64	9.39	9.47	10.18	488.8	61.53	67.59	65.29	60.12	60.36
206	80–30–F	23580	9.28	8.54	8.64	9.16	683.5	56.32	97.04	94.95	93.96	92.10
208	80–40–F	29453	11.59	7.01	7.09	7.59	853.7	46.28	120.23	116.17	116.98	111.90
209	160–20–F	26780	10.54	7.71	7.71	8.29	776.2	50.90	53.07	54.45	50.32	52.42
210	160–23–F	28713	11.30	6.94	7.01	7.43	832.2	45.74	59.08	58.67	56.33	56.59
211	160–27–F	31361	12.34	6.12	6.20	6.64	909.0	40.23	60.44	63.12	58.92	58.06
212	160–26–F	30620	12.05	6.48	6.52	6.96	887.5	41.81	64.31	63.40	59.33	59.15
213	160–40–P	29710	11.69	6.51	6.60	7.04	861.2	42.62	54.92	56.17	51.29	51.55
214	40–20–F								78.43	75.44	74.24	70.86
215	80–20–F								74.72	69.16	66.72	64.02
216	80–40–F								124.46	116.22	113.89	110.10
217	160–40–P	29190	11.49	7.27	7.34	7.89	846.1	48.37	50.82	50.95	47.59	46.03
218	160–40–P	29352	11.55	6.45	6.51	6.94	850.8	42.55	53.41	58.62	50.95	51.11
219	160–30–P	28712	11.29	6.97	7.03	7.45	832.2	45.03	57.84	57.68	53.80	55.68
220	160–26–P	28280	11.18	7.11	7.16	7.58	819.7	45.52	60.01	57.72	53.31	56.80
221	120–35–F								91.55	90.72	90.50	84.47
222	120–40–F								93.58	90.96	86.71	84.88

Test Number	Laboratory Designation	Engines									
		Mean Effective Pressure, Pounds Per Square Inch				Receiver		Number of Expansions			
		Low Pressure Cylinder				Pressure		Right Side		Left Side	
		Right Side		Left Side		Right Side	Left Side				
		Head End	Crank End	Head End	Crank End			Head End	Crank End	Head End	Crank End
		355	356	357	358	359	360	361	362	363	364
201	40–20–F							2.25	2.37	2.47	2.60
202	40–30–F							1.81	2.07	1.96	2·18
203	40–40–F							1.63	1.78	1.74	1.71
204	80–45–F							1.52	1.70	1.66	1.71
205	80–20–F							2.55	2.68	2.41	2.73
206	80–30–F							1.91	2.03	1.84	2.02
208	80–40–F							1.57	1.76	1.70	1.78
209	160–20–F							2.06	2.27	2.28	2.31
210	160–23–F							2.10	2.25	2.15	2.27
211	160–27–F							1.95	1.91	2·00	2.03
212	160–26–F							1.88	2.01	2.14	2.00
213	160–40–P							1.71	1.71	1.70	1.83
214	40–20–F							2.35	2.46	2.50	2.61
215	80–20–F							2.34	2.55	2.57	2.53
216	80–40–F							1.60	1.84	1.75	1.82
217	160–40–P							1.63	1.71	1.75	1.69
218	160–40–P							1.70	1.69	1.71	1.72
219	160–30–P							1.77	1.83	1.85	1.83
220	160–26–P							1.89	2.11	2.29	2.23
221	120–35–F							1.74	1.82	1.82	1.85
222	120–40–F							1.71	1.76	1.80	1.87

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.
LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

Test Number	Laboratory Designation	Engines: Indicated Horse Power: High Pressure Cylinder: Right Side: Head End	Crank End	Left Side: Head End	Crank End	Low Pressure Cylinder: Right Side: Head End	Crank End	Left Side: Head End	Crank End	Division of Power: High Pressure Cylinder: Right Side	Left Side	Low Pressure Cylinder: Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
201	40–20–F	77.2	74.0	76.2	71.8					151.3	148.1		
202	40–30–F	114.2	102.9	112.5	104.8					217.1	217.3		
203	40–40–F	145.4	136.8	138.9	129.3					282.2	268.2		
204	80–45–F	239.6	222.9	227.2	211.3					462.6	438.6		
205	80–20–F	142.7	133.5	127.2	123.6					276.2	250.8		
206	80–30–F	203.9	193.2	197.8	187.7					397.1	385.5		
208	80–40–F	252.4	236.1	246.1	227.9					488.5	474.0		
209	160–20–F	221.8	220.4	210.7	212.6					442.2	423.3		
210	160–23–F	248.0	238.5	236.8	230.5					486.4	467.3		
211	160–27–F	253.8	256.6	247.9	236.5					510.4	484.4		
212	160–26–F	270.5	258.3	267.1	258.0					528.8	525.1		
213	160–40–P	231.1	228.9	216.3	210.5					460.0	426.8		
214	40–20–F	81.5	75.9	77.3	71.4					157.3	148.7		
215	80–20–F	157.1	140.8	140.5	130.6					297.9	271.1		
216	80–40–F	259.6	234.7	238.0	222.8					494.3	460.8		
217	160–40–P	212.3	206.1	198.3	182.8					418.4	381.1		
218	160–40–P	224.4	218.1	144.4	208.3					442.5	422.7		
219	160–30–P	241.0	232.6	224.6	225.1					473.6	449.8		
220	160–26–P	252.0	234.7	224.3	231.4					486.7	455.7		
221	120–35–F	285.5	274.1	282.9	255.7					559.6	538.6		
222	120–40–F	293.1	275.9	272.1	256.4					569.0	528.5		

Test Number	Laboratory Designation	Engines: Division of Power: Total: Right Side	Left Side	Total I. H. P.	Consumed Per I. H. P., Hour: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	Locomotive: Dynamometer Horse Power	Pounds Per D. H. P., Hour: Of Dry Coal	Of Dry Steam	B. T. U. Per D. H. P. Hour
		377	378	379	380	381	382	383	384	385	386
201	40–20–F	151.3	148.1	299.4	3.53	29.56	52422	232.5	4.55	38.07	67516
202	40–30–F	217.1	217.3	434.4	3.10	27.78	45092	401.7	3.36	30.05	48775
203	40–40–F	282.2	268.2	550.4	3.55	27.31	53792	491.8	3.98	30.57	60200
204	80–45–F	462.6	438.6	901.1	4.88	26.11	72405	817.5	5.39	28.79	79805
205	80–20–F	276.2	250.8	527.0	3.28	25.89	48715	463.2	3.73	29.46	55440
206	80–30–F	397.1	385.5	782.6	3.41	24.55	50491	732.0	3.65	26.26	53982
208	80–40–F	488.5	474.0	962.5	4.22	24.93	62410	894.6	4.54	26.82	67141
209	160–20–F	442.2	423.3	865.6	3.86	25.11	57159	785.3	4.25	27.69	62936
210	160–23–F	486.4	467.3	953.7	4.22	24.67	62371	850.8	4.73	27.66	69840
211	160–27–F	510.4	484.4	994.8	5.02	26.04	74625	860.5	5.80	30.11	86265
212	160–26–F	528.8	525.1	1053.9	4.38	23.92	66060	896.8	5.16	28.12	77710
213	160–40–P	460.0	426.8	886.8	5.01	27.64	74820	801.6	5.54	30.58	82775
214	40–20–F	157.3	148.7	306.0				251.8			
215	80–20–F	297.9	271.1	569.0				474.6			
216	80–40–F	494.3	460.8	955.1				874.3			
217	160–40–P	418.4	381.1	799.5	4.91	30.11	71928	759.4	5.17	31.70	75723
218	160–40–P	442.5	422.7	865.2	5.14	28.01	75967	843.5	5.28	28.73	77971
219	160–30–P	473.6	449.8	923.4	4.34	25.53	65432	837.4	4.78	28.15	72171
220	160–26–P	486.7	455.7	942.4	4.12	24.67	62573	807.8	4.81	28.78	73000
221	120–35–F	559.6	538.6	1098.2				957.3			
222	120–40–F	569.0	528.5	1097.6				999.3			

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.

LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY COMPANY.

Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	I. H. P. Per Square Foot of: Heating Surface	Grate Surface	D. H. P. Per Square Foot of: Heating Surface	Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
201	40–20–F	2.30	19.22	34098	.1178	8.87	.0915	6.89	14841	66.87	16.03	3316
202	40–30–F	1.70	15.18	24632	.1710	12.87	.1581	11.90	21481	82.69	7.81	1616
203	40–40–F	2.01	15.43	30399	.2166	16.30	.1935	14.57	27450	58.64	14.14	2924
204	80–45–F	2.59	13.87	38459	.3546	26.69	.3217	24.21	22538	83.62	10.11	2091
205	80–20–F	1.88	14.88	28002	.2074	15.61	.1823	13.72	13102	63.78	7.67	1586
206	80–30–F	1.84	13.26	27223	.3080	23.18	.2880	21.68	19552	50.60	6.11	1264
208	80–40–F	2.29	13.54	33861	.3788	28.51	.3520	26.50	24070	67.90	8.21	1448
209	160–20–F	2.15	13.98	31830	.3406	25.64	.3092	23.27	10868	80.26	4.87	1008
210	160–23–F	2.39	13.97	35305	.3753	28.25	.3348	25.20	11927	102.88	6.22	1288
211	160–27–F	2.93	15.20	43560	.3915	29.46	.3386	25.49	12436	134.13	8.11	1677
212	160–26–F	2.60	14.20	39210	.4147	31.22	.3529	26.56	13150	157.10	9.48	1961
213	160–40–P	2.80	15.44	41810	.3490	26.27	.3154	23.74	11061	85.22	5.14	1063
214	40–20–F				.1204	9.06	.0991	7.46	15464	54.18	13.24	2739
215	80–20–F				.2239	16.86	.1868	14.06	14205	94.43	11.40	2358
216	80–40–F				.3758	28.29	.3440	25.90	24089	80.82	9.83	2034
217	160–40–P	2.57	15.75	37621	.3146	23.68	.2988	22.49	10053	40.11	2.44	504
218	160–40–P	2.66	14.51	39355	.3405	25.63	.3319	24.98	10818	21.71	1.31	271
219	160–30–P	2.41	14.22	36445	.3633	27.35	.3295	24.80	11630	85.99	5.24	1083
220	160–26–P	2.43	14.54	36877	.3709	27.92	.3179	23.93	11779	134.64	8.14	1683
221	120–35–F				.4321	32.53	.3765	28.35	18479	140.86	11.46	2369
222	120–40–F				.4319	32.51	.3932	29.60	18393	98.28	7.96	1647

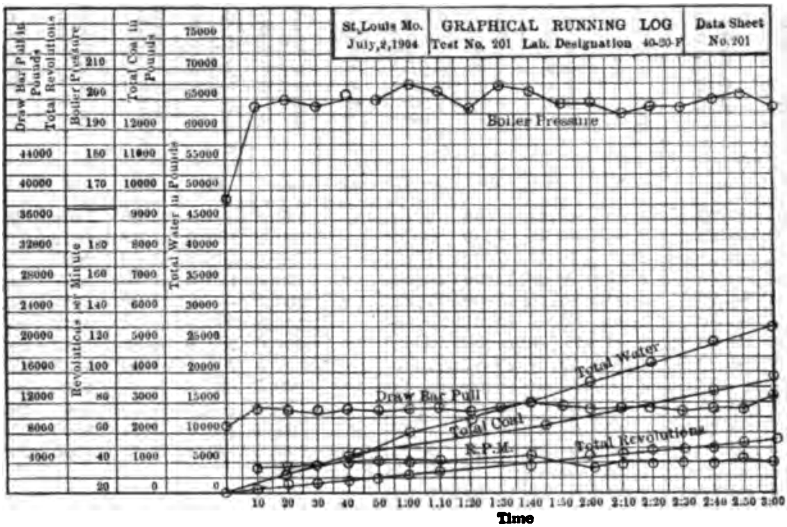
Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
201	40–20–F	77.66	3.77	522.9	7.33	460	346.9				7–2–04
202	40–30–F	92.47	5.22	369.9	5.18	795	490.3				7–7–04
203	40–40–F	89.35	4.23	321.3	4.50	974	564.4				7–28–04
204	80–45–F	90.72	3.19	177.1	2.48	1696	1023.8				7–27–04
205	80–20–F	87.90	4.59	303.9	4.26	917	596.7				7–2–04
206	80–30–F	93.53	4.72	293.0	4.11	1449	619.1				7–9–04
208	80–40–F	92.94	3.79	150.0	2.10	1772	120.9				7–8–04
209	160–20–F	90.73	4.04	139.7	1.96	1555	129.8				7–9–04
210	160–23–F	89.21	3.64	132.1	1.85	1685	137.3				7–12–04
211	160–27–F	86.52	2.95	106.5	1.49	1705	170.2				7–11–04
212	160–26–F	85.09	3.27	164.0	2.30	1775	1105.3				7–25–04
213	160–40–P	90.39	3.06	186.2	2.61	1587	973.5				7–26–04
214	40–20–F	82.29									8–2–04
215	80–20–F	83.41									8–2–04
216	80–40–F	91.54									8–2–04
217	160–40–P	94.99	3.37	209.7	2.94	1528	864.4				7–15–04
218	160–40–P	97.50	3.27	196.8	2.76	1670	921.3				7–18–04
219	160–30–P	90.69	3.53	187.5	2.63	1658	966.9				7–23–04
220	160–26–P	85.72	3.49	189.8	2.66	1599	955.1				7–26–04
221	120–35–F	87.17		151.8	2.13		1194.0				7–16–04
222	120–40–F	91.94		153.6	2.15		1180.4				7–27–04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 734.

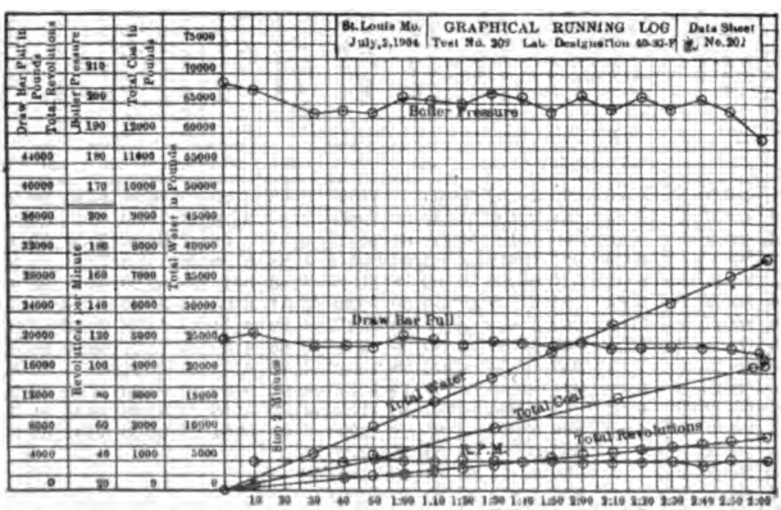
Lake Shore and Michigan Southern Railway Company.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft, Front of Diaphragm, Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	208	217	220	222	338	341
201	40–20–F	3.00	40.34	7.56	19.15	Full	192.8	——	1.38	1109	9285
202	40–30–F	3.00	40.46	7.59	30.73	"	199.9	199.9	2.38	1412	12638
203	40–40–F	2.17	40.11	7.52	41.27	"	199.6	198.4	3.06	2027	15549
204	80–45–F	2.37	79.99	14.99	43.93	"	178.0	175.5	5.70	4468	23886
205	80–20–F	3.00	80.46	15.09	17.32	"	200.3	——	2.90	1781	14065
206	80–30–F	3.00	80.07	15.01	30.66	"	201.8	200.3	4.15	2729	19665
208	80–40–F	3.00	80.00	14.99	40.69	"	204.0	202.6	5.85	4152	24544
209	160–20–F	3.00	159.31	29.87	21.07	"	201.5	201.1	4.89	3435	22335
210	160–23–F	2.15	159.94	29.98	23.32	"	198.5	196.3	5.33	4096	23975
211	160–27–F	1.17	160.01	30.00	28.90	"	178.4	175.3	5.73	5061	26265
212	160–26–F	3.00	160.32	30.04	27.37	"	199.4	190.7	5.91	4695	25610
213	160–40–P	3.00	160.39	30.07	39.76	1.00	202.6	130.8	5.85	4505	24860
214	40–20–F	1.00	39.58	7.42	19.35	Full	198.4				
215	80–20–F	1.00	80.13	15.02	19.66	"	199.5				
216	80–40–F	1.00	79.49	14.90	40.11	"	198.7				
217	160–40–P	1.00	159.23	29.85	38.54	1.60	199.3	117.3	5.25	3975	24394
218	160–40–P	2.08	160.10	30.01	39.02	1.25	200.8	124.7	5.47	4509	24564
219	160–30–P	3.00	158.82	29.77	30.95	1.25	200.7	137.1	5.02	4079	24030
220	160–26–P	3.00	160.05	30.00	24.59	2.00	201.6	193.9	5.35	3950	23646
221	120–35–F	.50	118.90	22.28	35.70	Full	189.4		6.40		
222	120–40–F	.50	119.37	22.38	37.50	"	187.9		7.50		

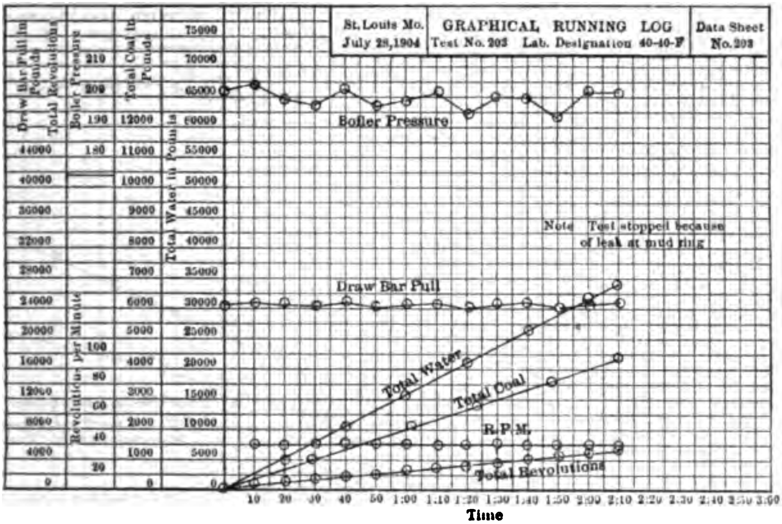
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		317	379	383	395	265	380	384	381	385	350	390
201	40–20–F	10.08	299.4	232·5	66.87	11531	3.58	4.55	29.56	38.07	65.20	3.77
202	40–30–F	10.74	434.4	401.7	32.69	19860	3.10	3.36	27.78	30.05	71.34	5.22
203	40–40–F	9.18	550.4	491.8	58.64	24522	3.55	3.98	27.31	30.57	58.57	4.23
204	80–45–F	6.35	901.1	817.5	83.62	20444	4.88	5.39	26.11	28.79	41.53	3.19
205	80–20–F	9.47	527.0	463.2	63.78	11515	3.28	3.73	25.89	29.46	61.53	4.59
206	80–30–F	8.64	782.6	732.0	50.60	18288	3.41	3.65	24.55	26.26	56:32	4.72
208	80–40–F	7.09	962.5	894.6	67.90	22371	4.22	4.54	24.98	26.82	46.28	3.79
209	160–20–F	7.71	865.6	785.3	80.26	9861	3.86	4.25	25.11	27.69	50.90	4.04
210	160–23–F	7.01	953.7	850.8	102.88	10642	4.22	4.72	24.67	27.66	45.74	3.64
211	160–27–F	6.20	994.8	860.5	134.13	10755	5.02	5.80	26.04	30.11	40.23	2.95
212	160–26–F	6.52	1053.9	896.8	157.10	11188	4.38	5.16	23.92	28.12	41.81	3.27
213	160–40–P	6.60	886.8	801.6	85.22	9998	5.01	5.54	27.64	30.58	42.62	3.06
214	40–20–F		306.0	251.8	54.18	12725						
215	80–20–F		569.0	474.6	94.43	11847						
216	80–40–F		955.1	874.3	80.82	22001						
217	160–40–P	7.34	799.5	759.4	40.11	9540	4.91	5.17	30.11	31.70	48.37	3.37
218	160–40–P	6.51	865.2	843.5	21.71	10538	5.14	5.28	28.01	28.73	42.55	3.27
219	160–30–P	7.03	923.4	837.4	85.99	10546	4.34	4.78	25.53	28.15	45.03	3.53
220	160–26–P	7.16	942.4	807.8	134.64	10096	4.12	4.81	24.67	28.78	45.52	3.49
221	120–35–F		1098.2	957.3	140.86	16104						
222	120–40–F		[illegible]	[illegible]	[illegible]	[illegible]						



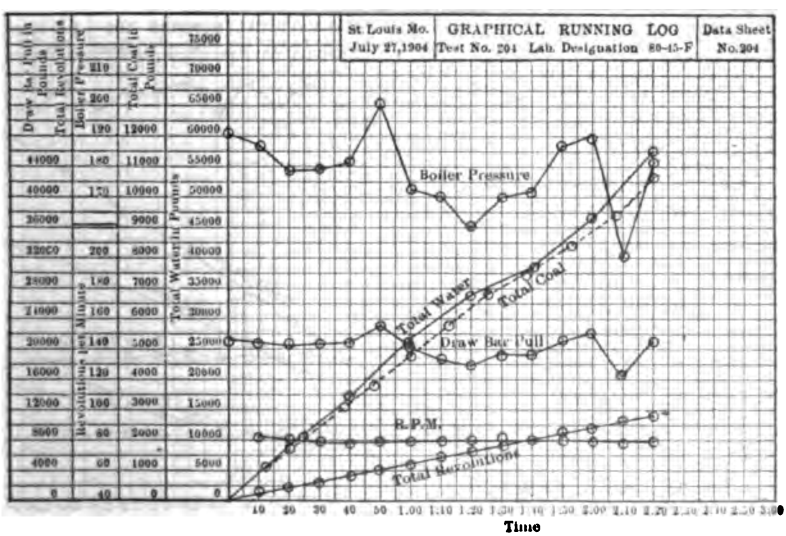
Test No. 201.



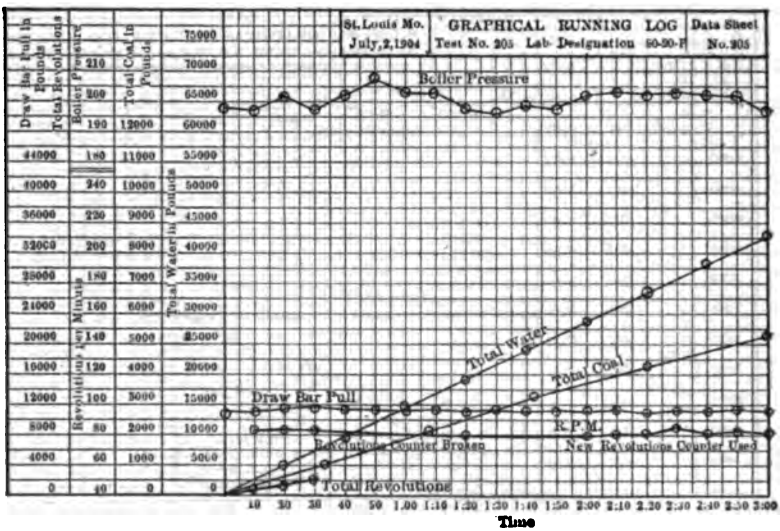
Test No. 202.



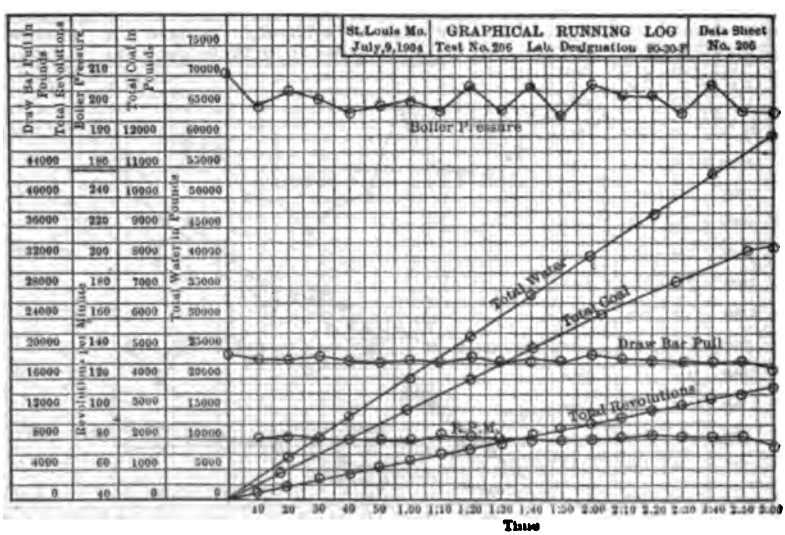
Test No. 203.



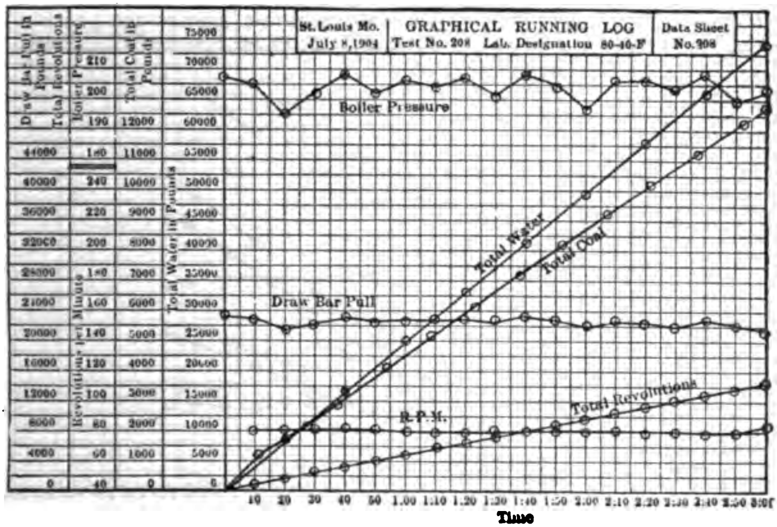
Test No. 204.



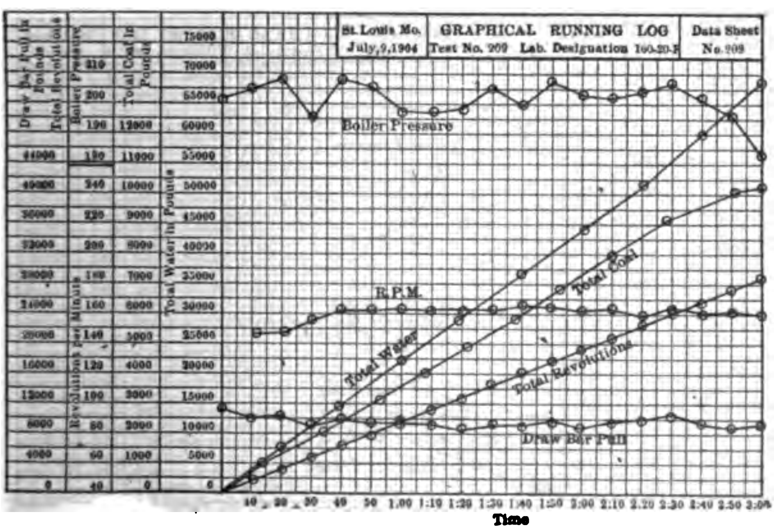
Test No. 205.



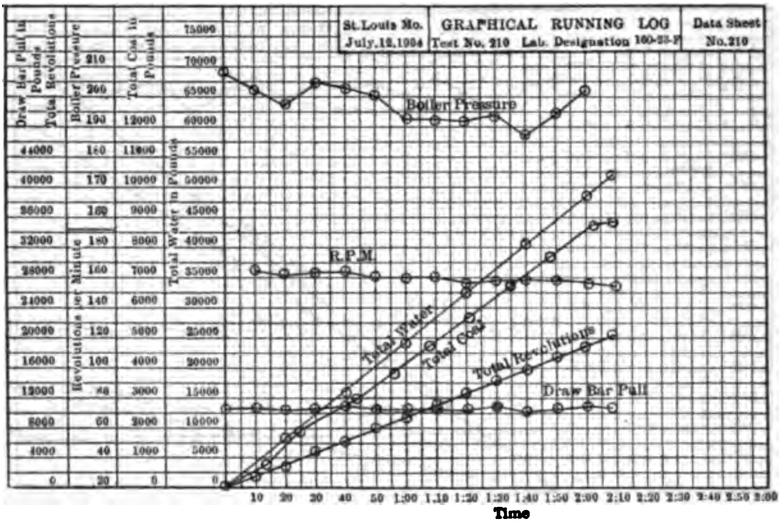
Test No. 206.



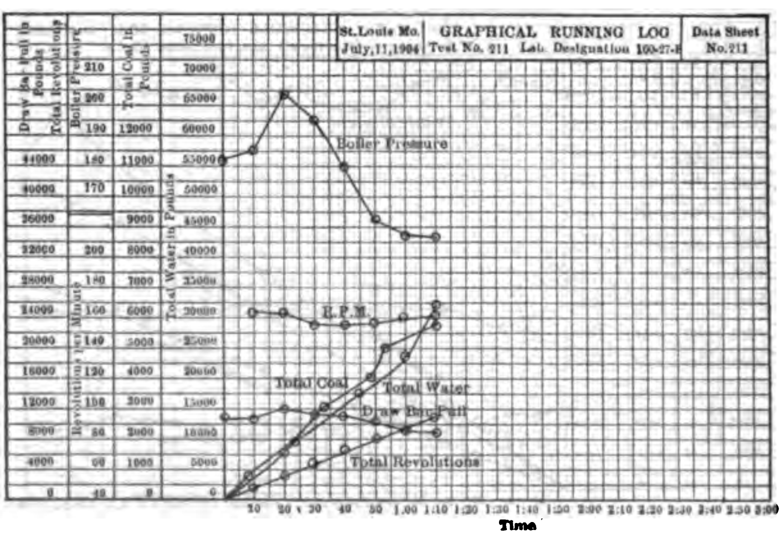
Test No. 208.



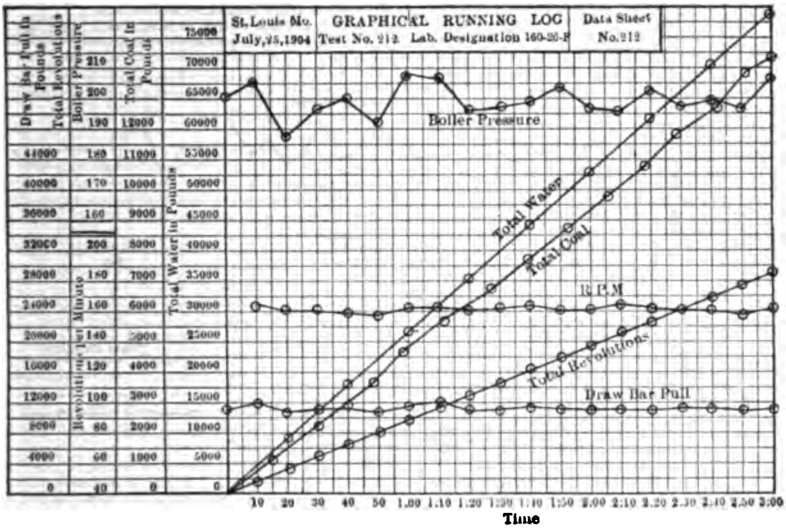
Test No. 209.



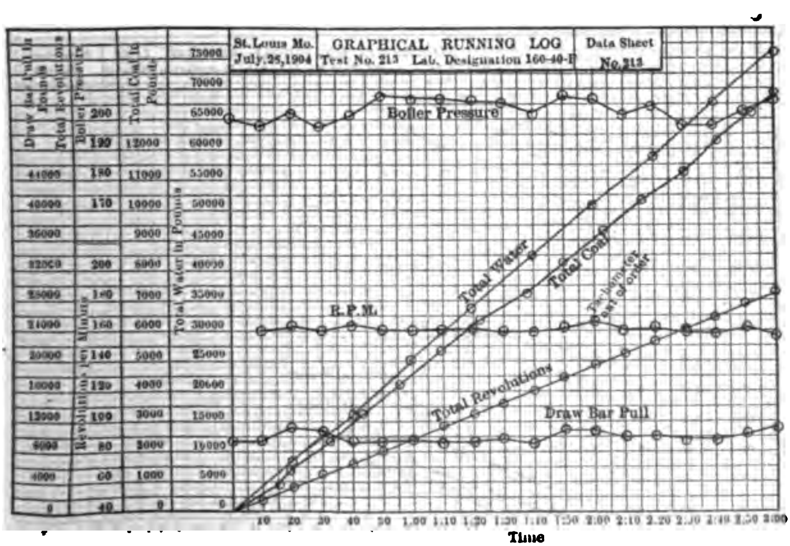
Test No. 210.



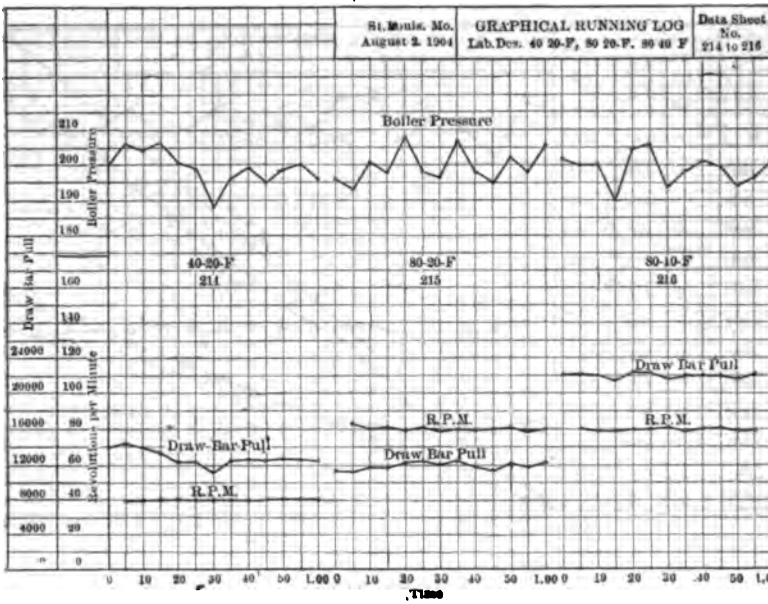
Test No. 211.



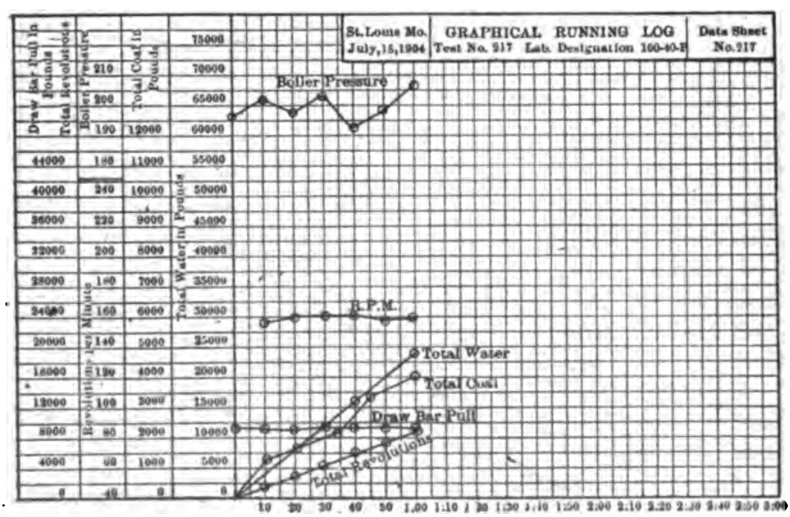
Test No. 212.



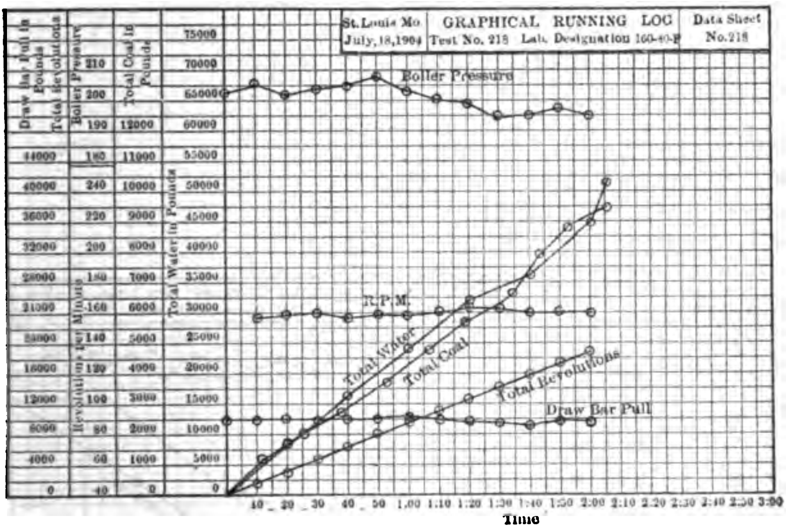
Test No. 213.



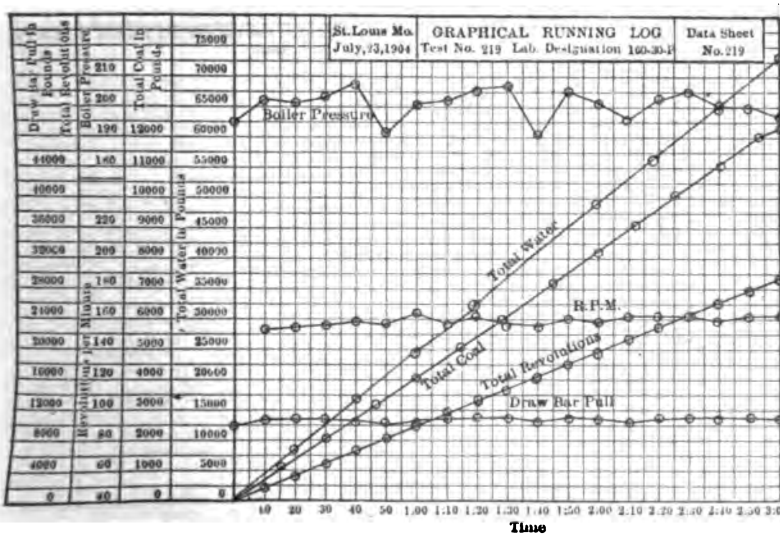
Tests No. 214 to 216.



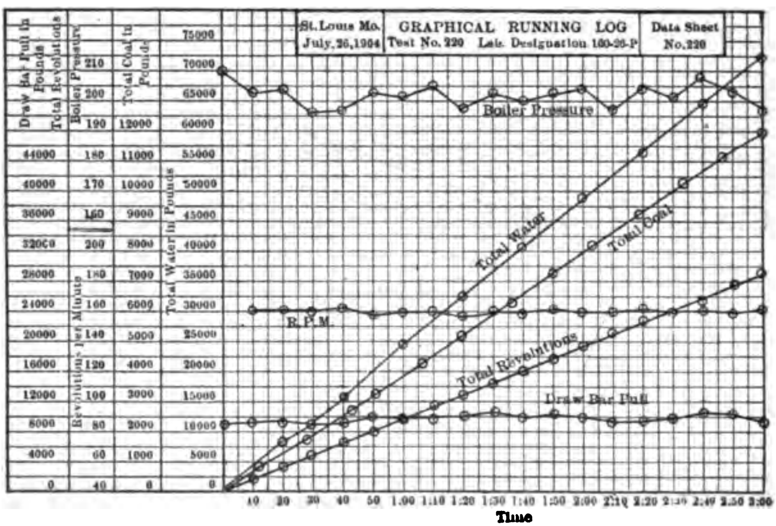
Test No. 217.



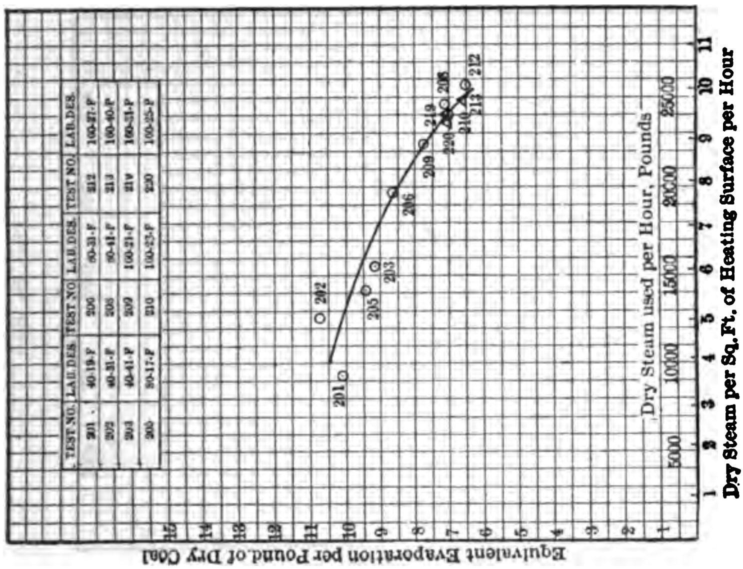
Test No. 218.



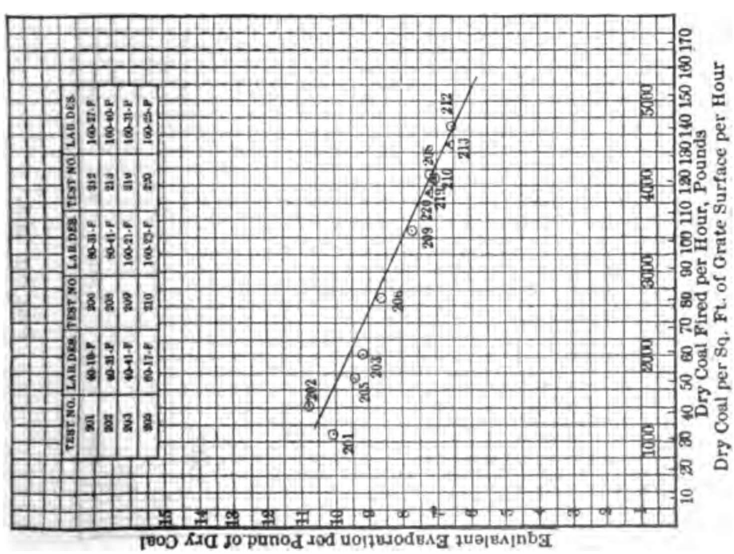
Test No. 219.


St. Louis Mo. July, 26, 1904
GRAPHICAL RUNNING LOG
Test No. 220 Lab. Designation 160-26-P
Data Sheet No. 220
Draw Bar Pull in Pounds
Total Revolutions
Boiler Pressure
Total Coal in Pounds
Total Water in Pounds
Revolutions per Minute
Boiler Pressure
Total Water
Total Coal
R.P.M.
Total Revolutions
Draw Bar Pull
Time

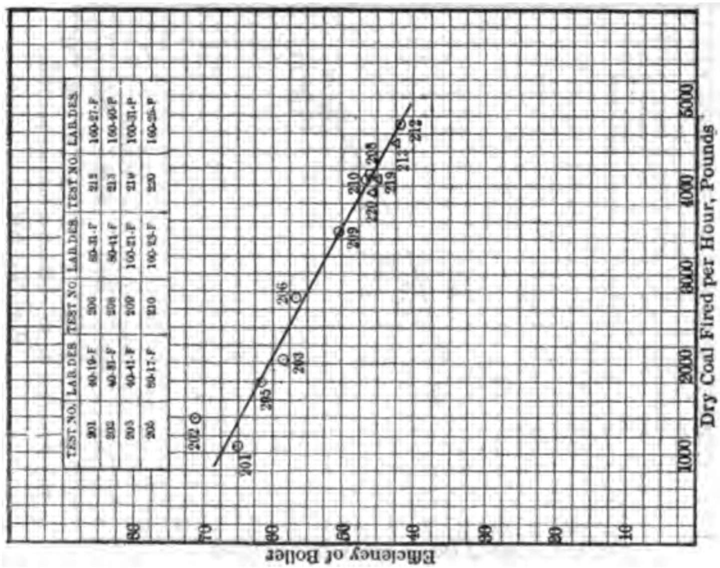
Test No. 220.



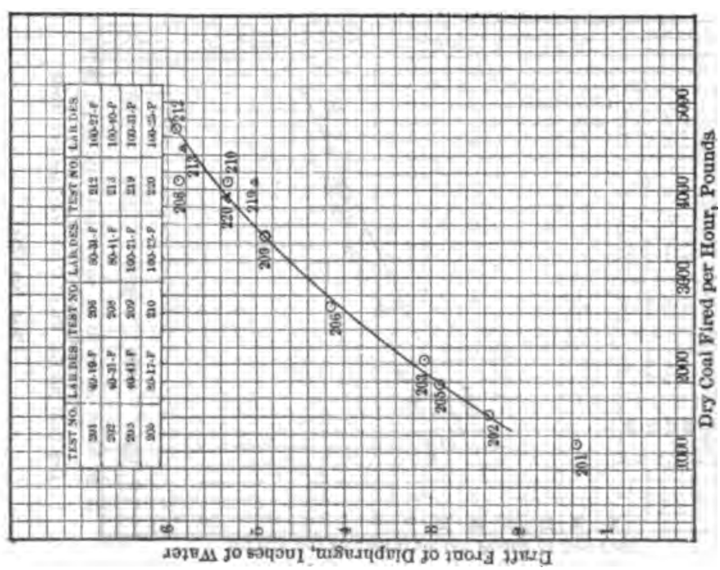
Plot No. 202.



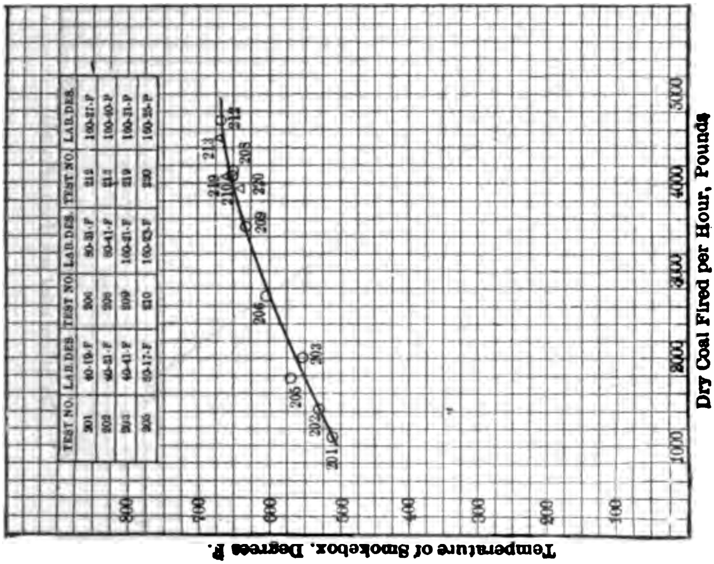
Plot No. 201.



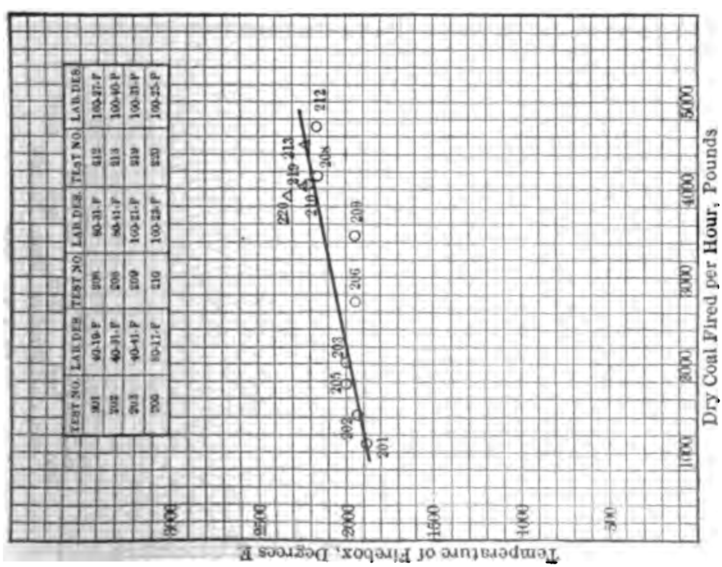
Plot No. 204.



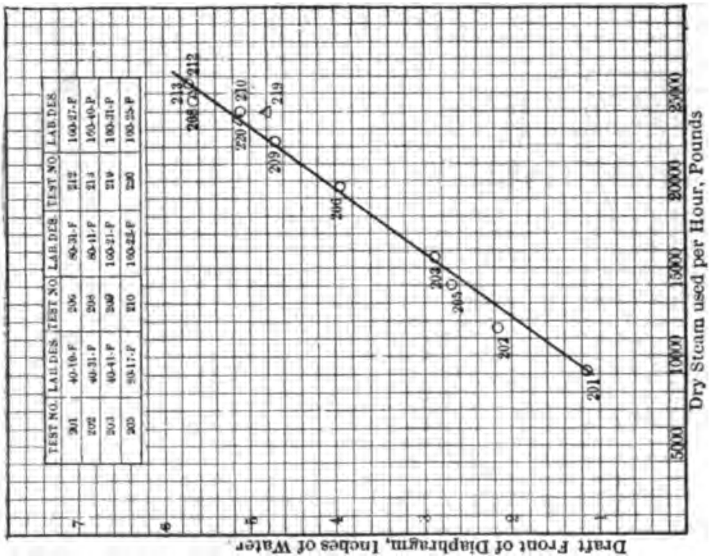
Plot No. 203.



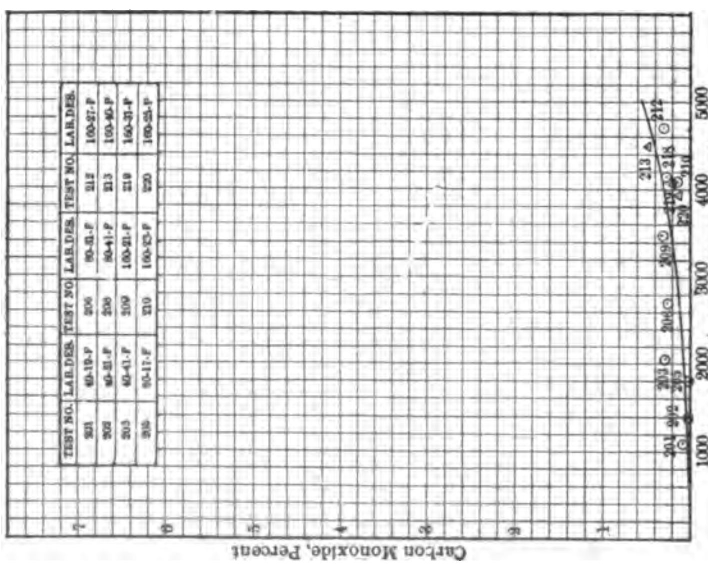
Plot No. 206.



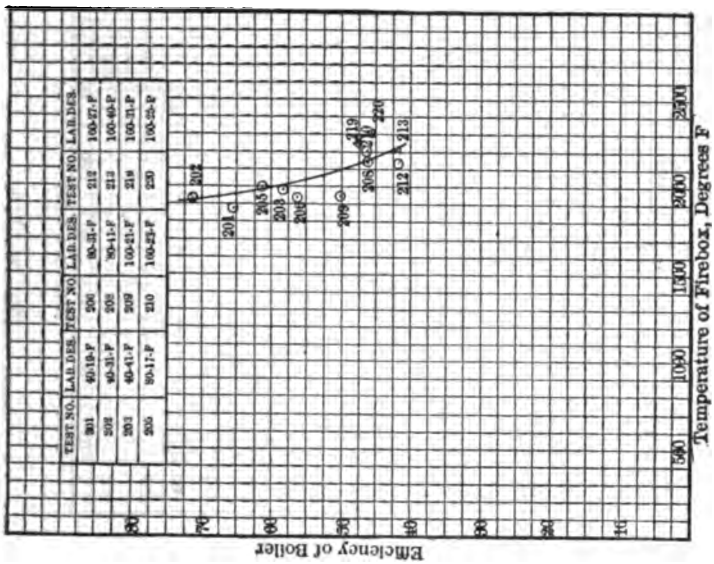
Plot No. 205.



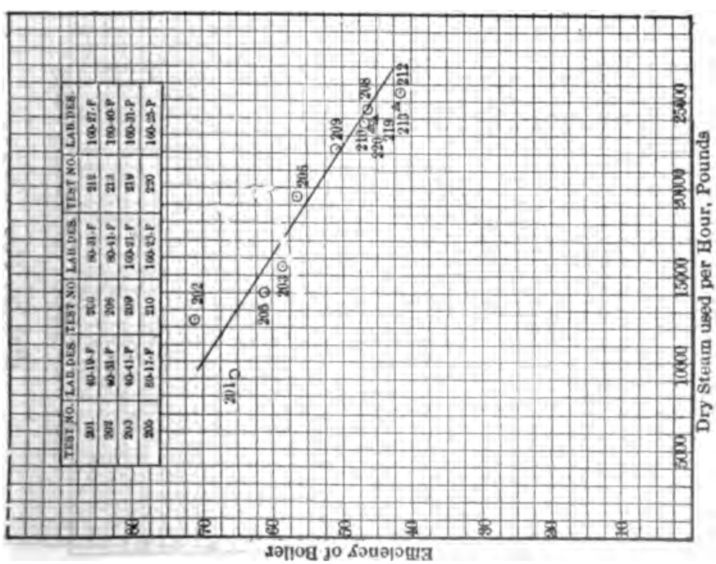
Plot No. 208.



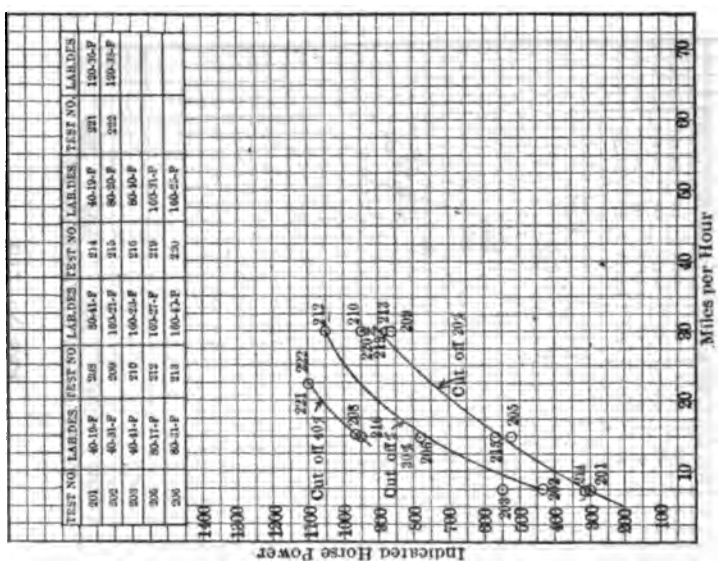
Plot No. 207.



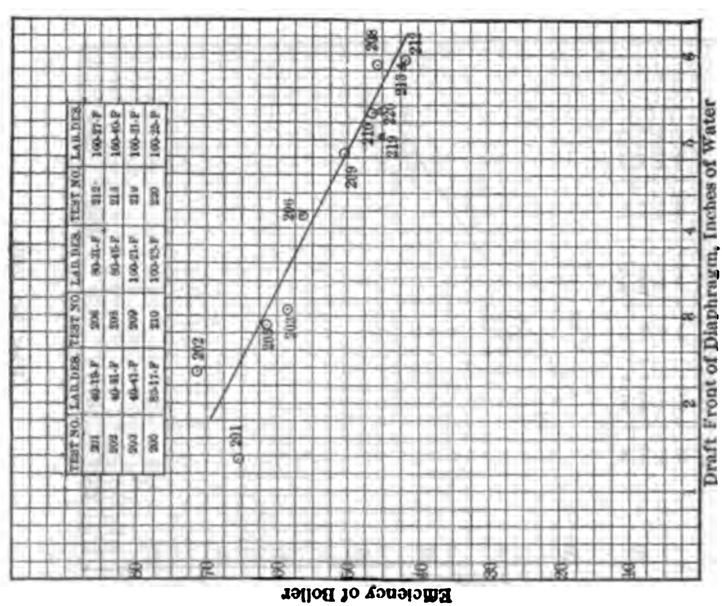
Plot No. 210.



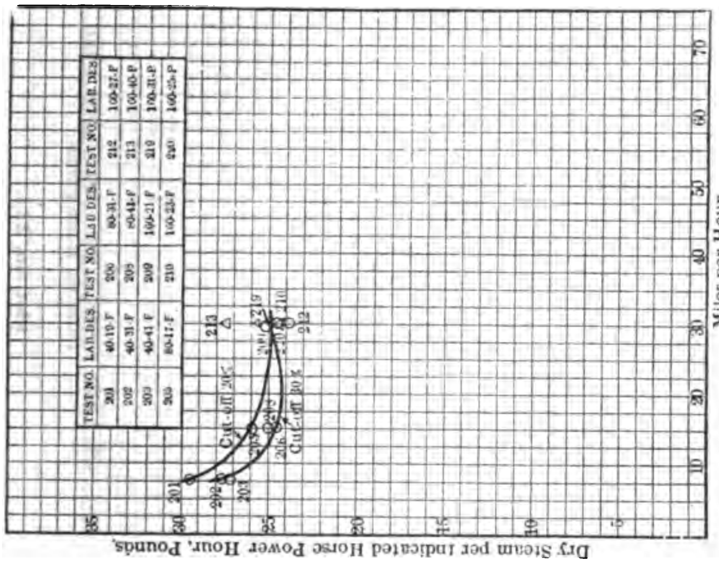
Plot No. 209.



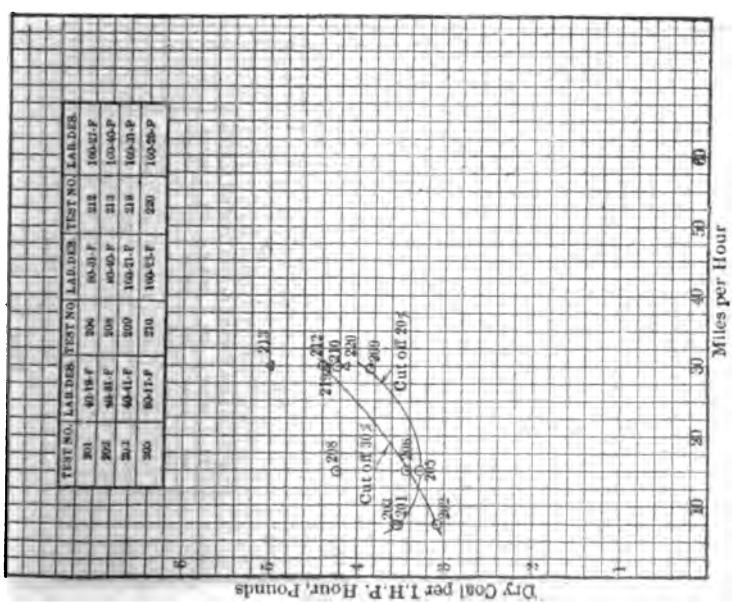
Plot No. 220.



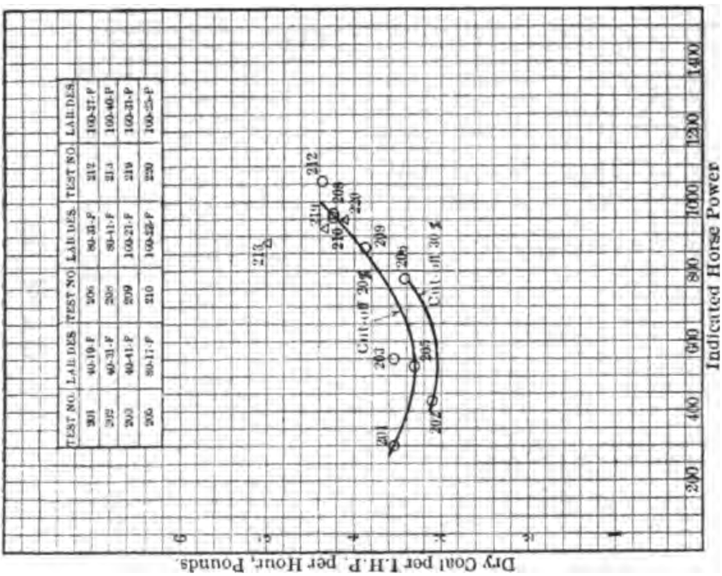
Plot No. 211.



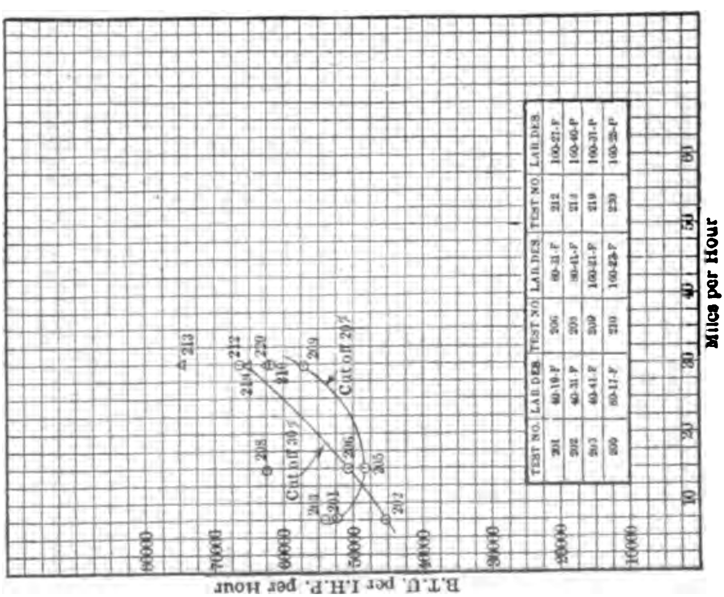
Plot No. 222.



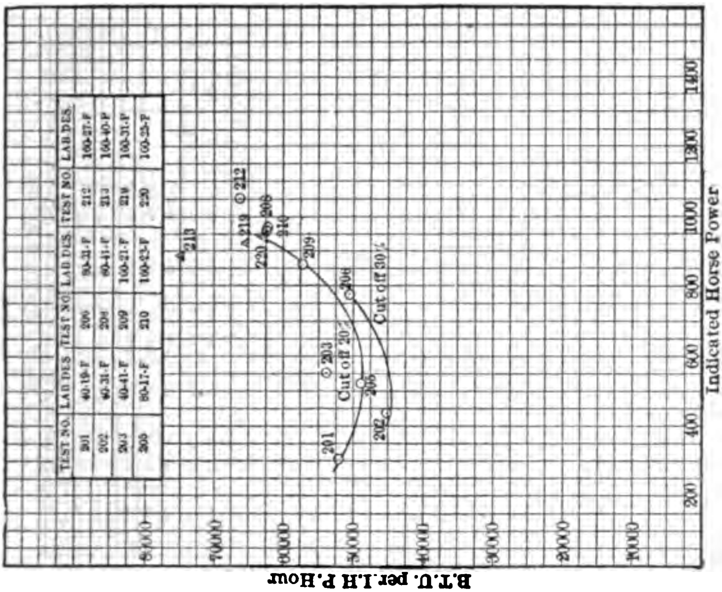
Plot No. 221.



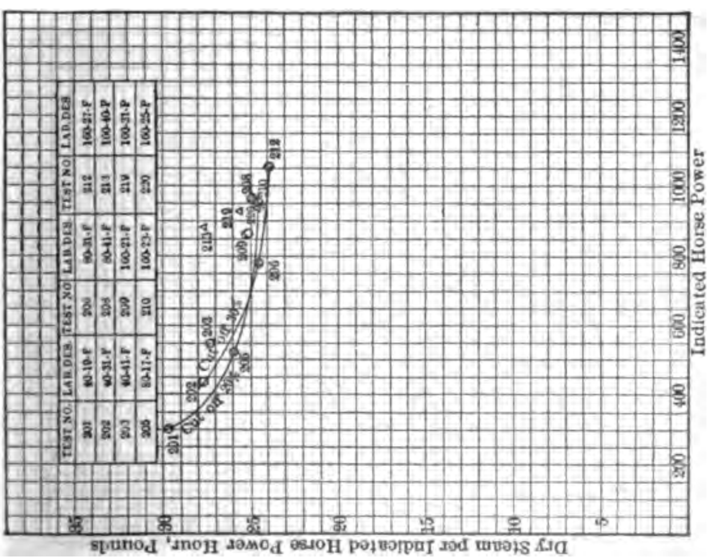
Plot No. 224.



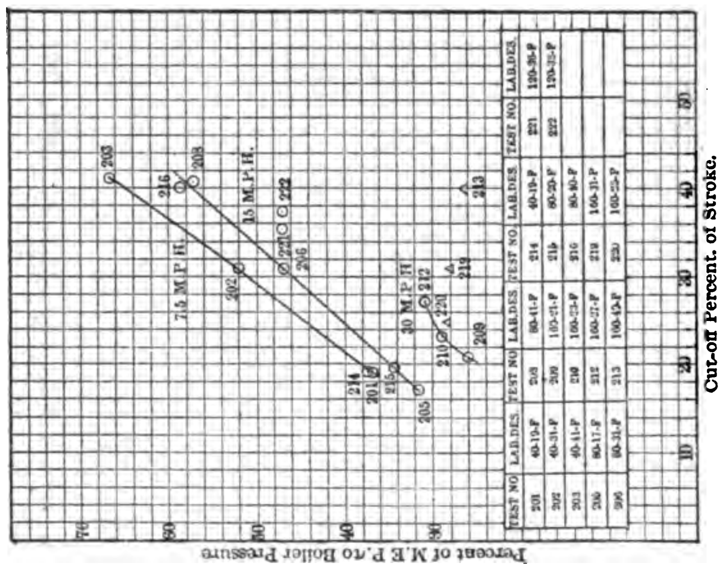
Plot No. 223.



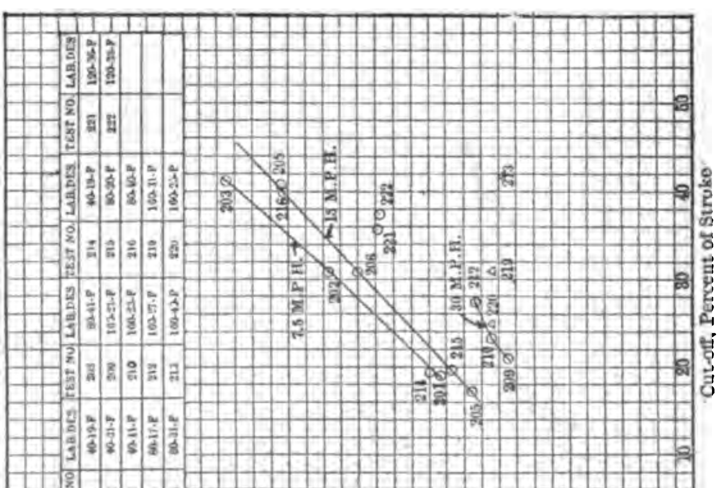
Plot No. 226.



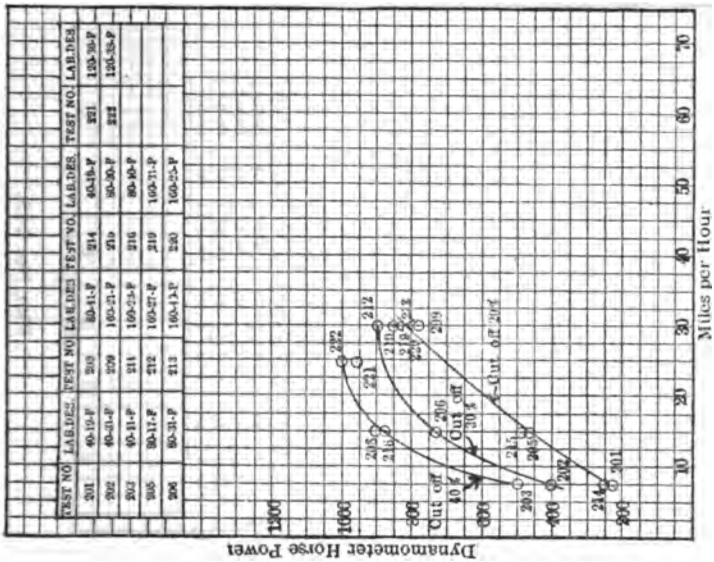
Plot No. 225.



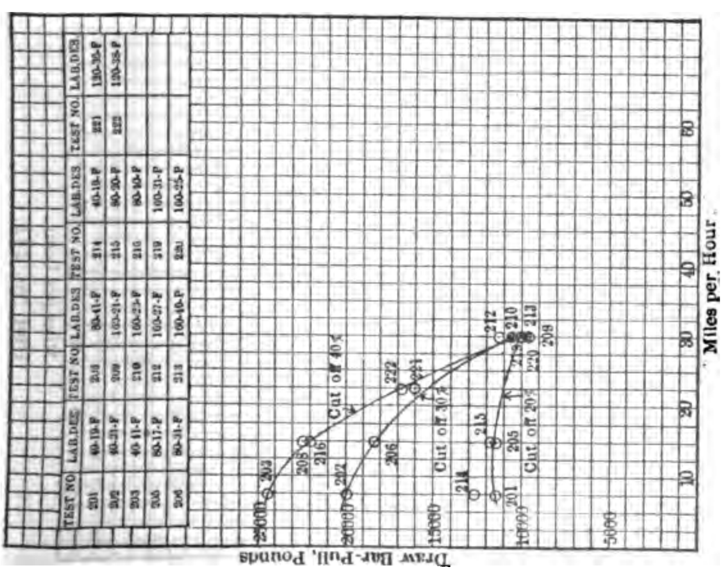
Plot No. 228.



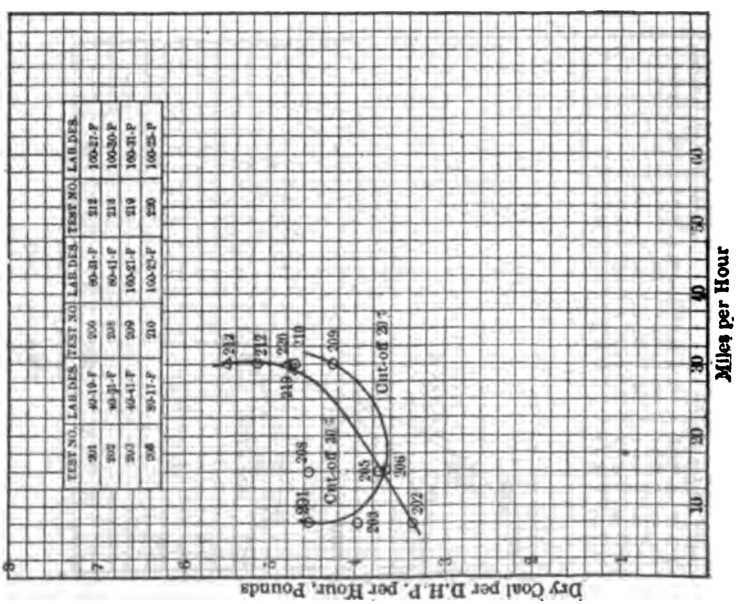
Plot No. 227.



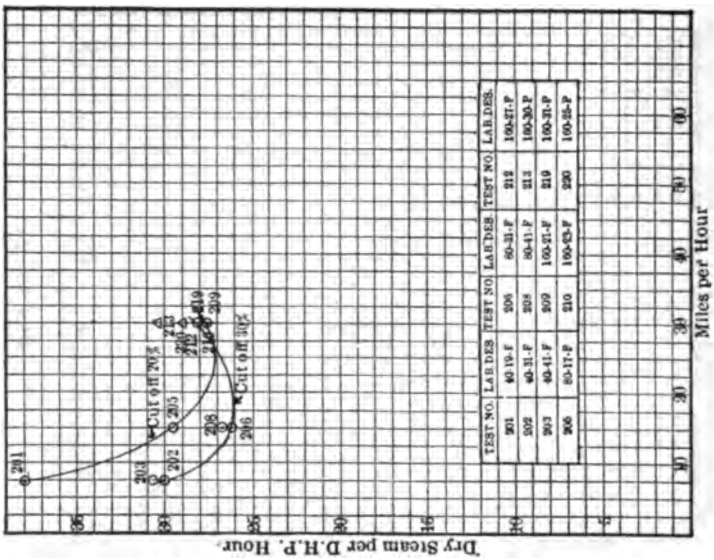
Plot No. 241.



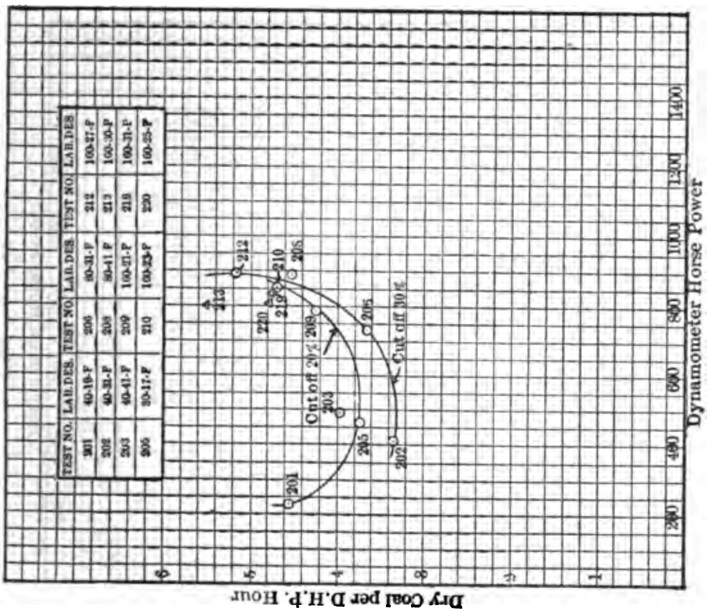
Plot No. 240.



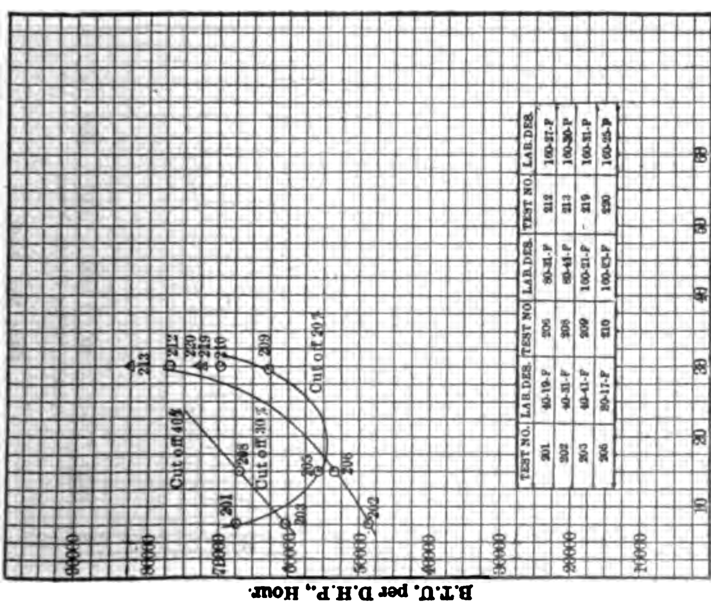
Plot No. 242.



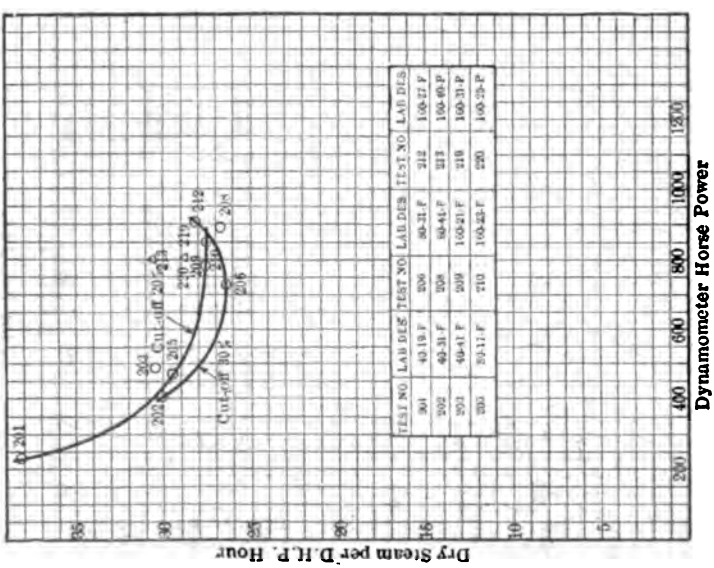
Plot No. 243.



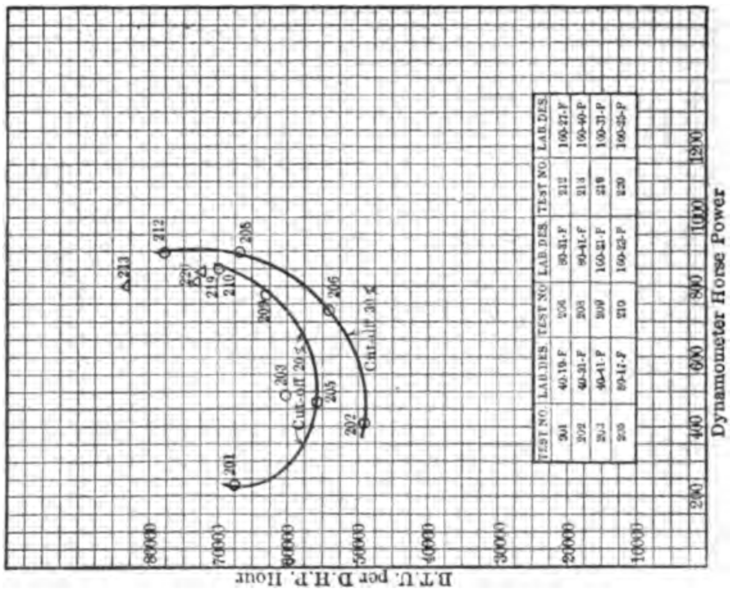
Plot No. 245.



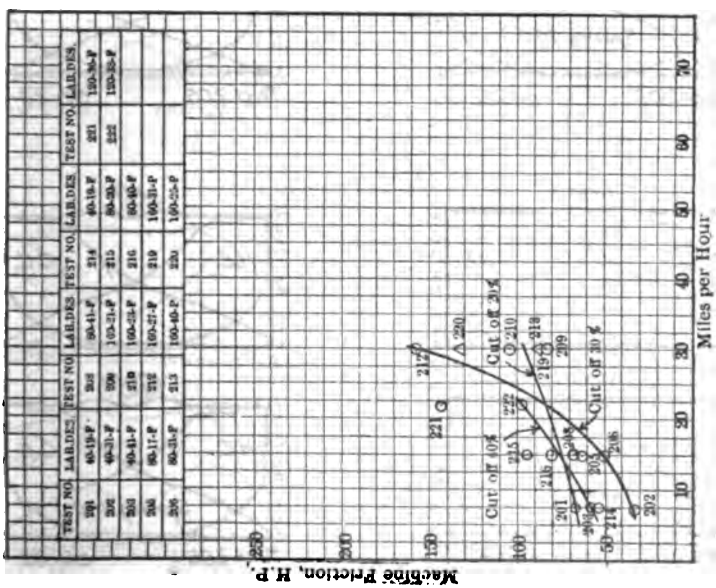
Plot No. 244.



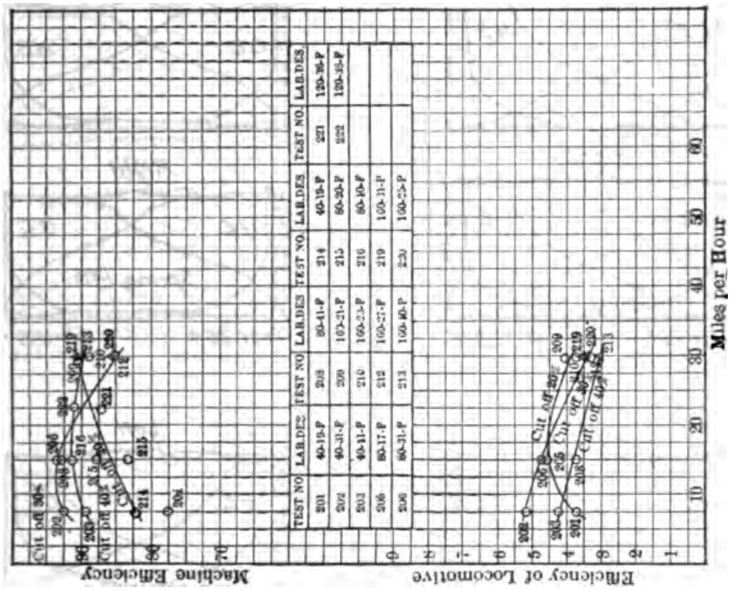
Plot No. 246.



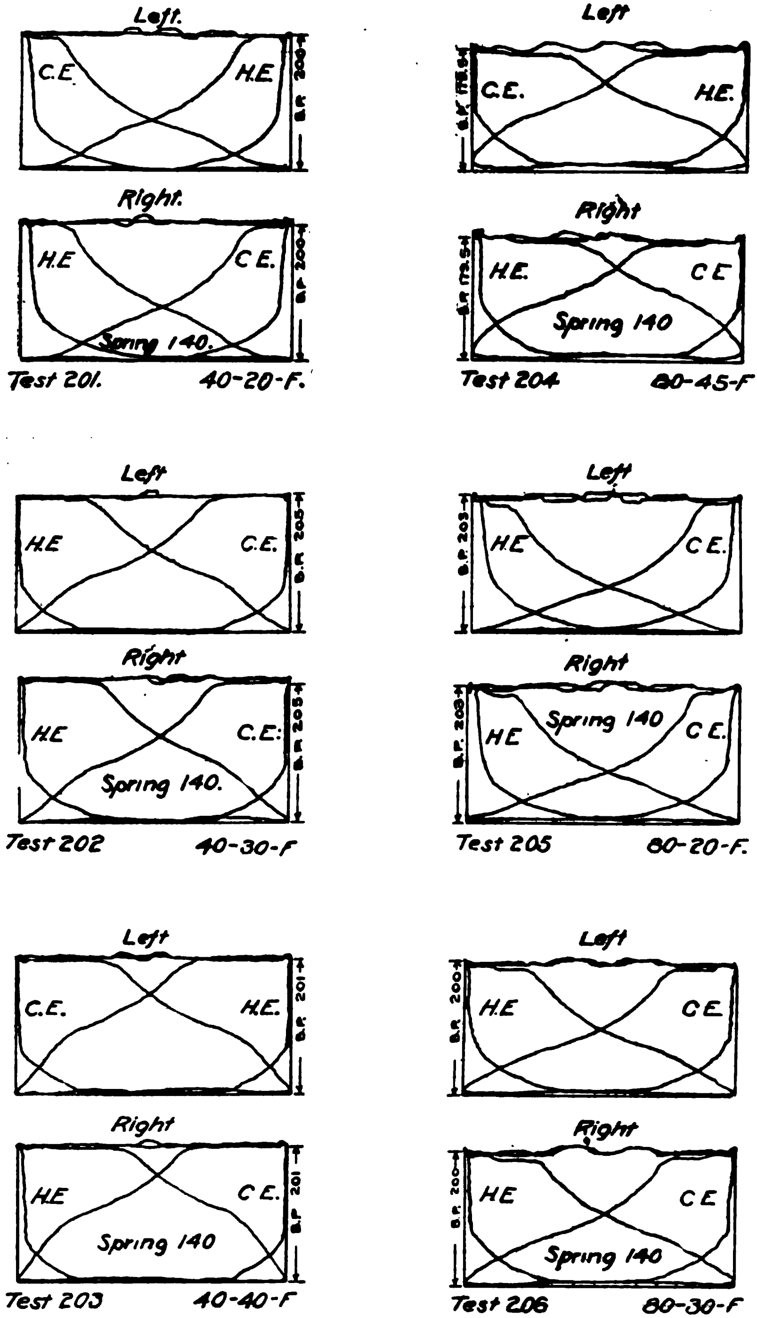
Plot No. 247.



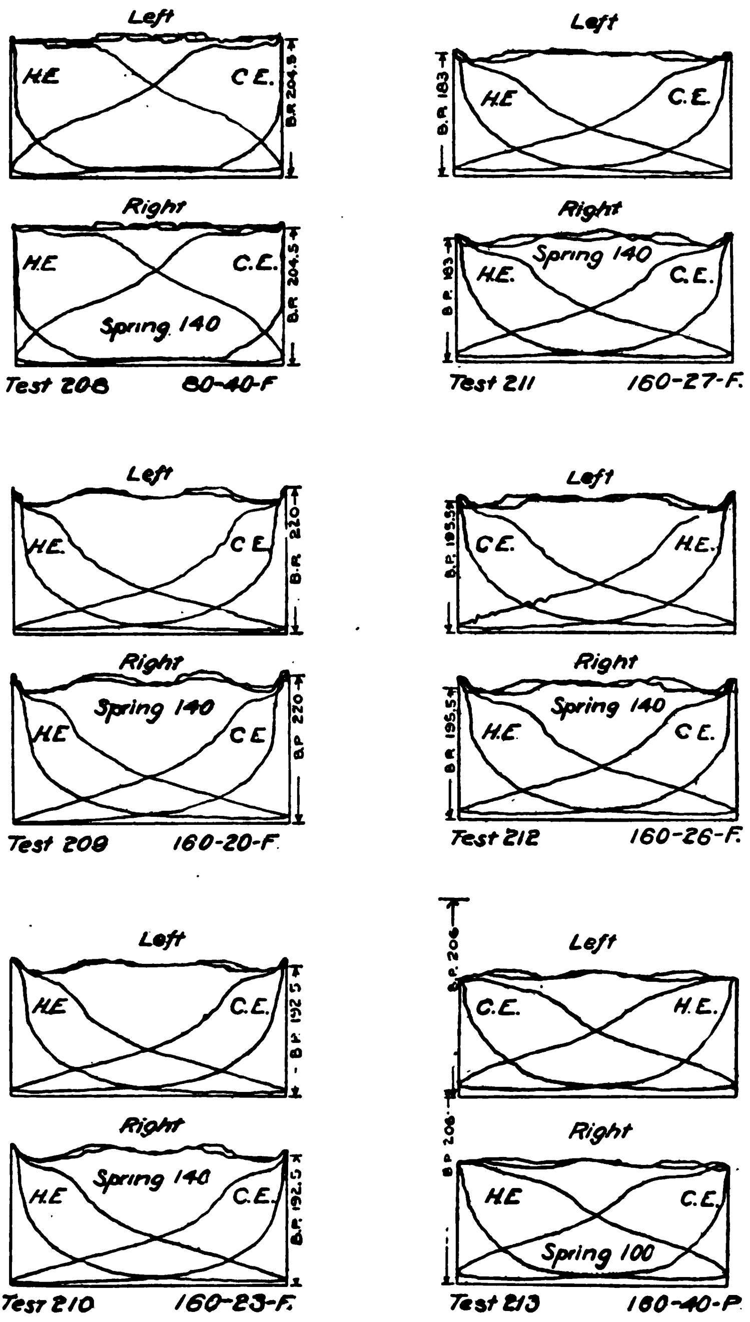
Plot No. 248.



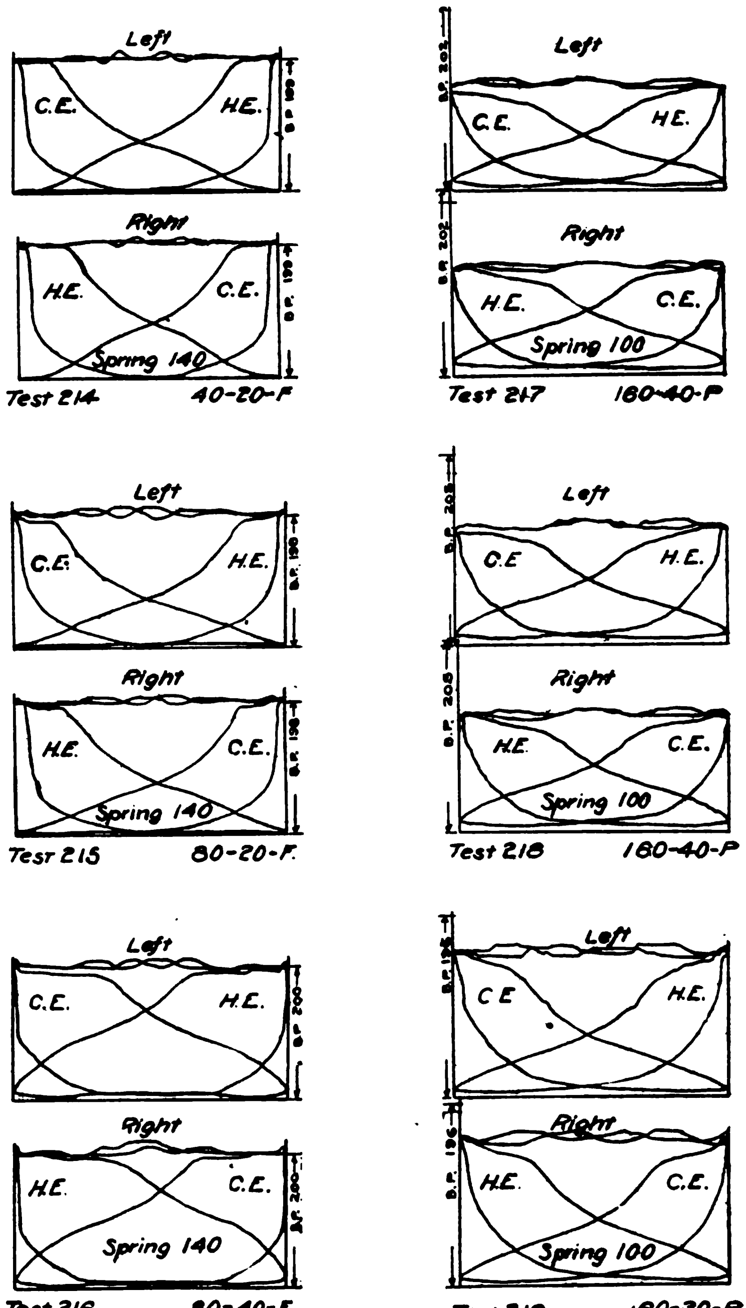
Plot No. 249.



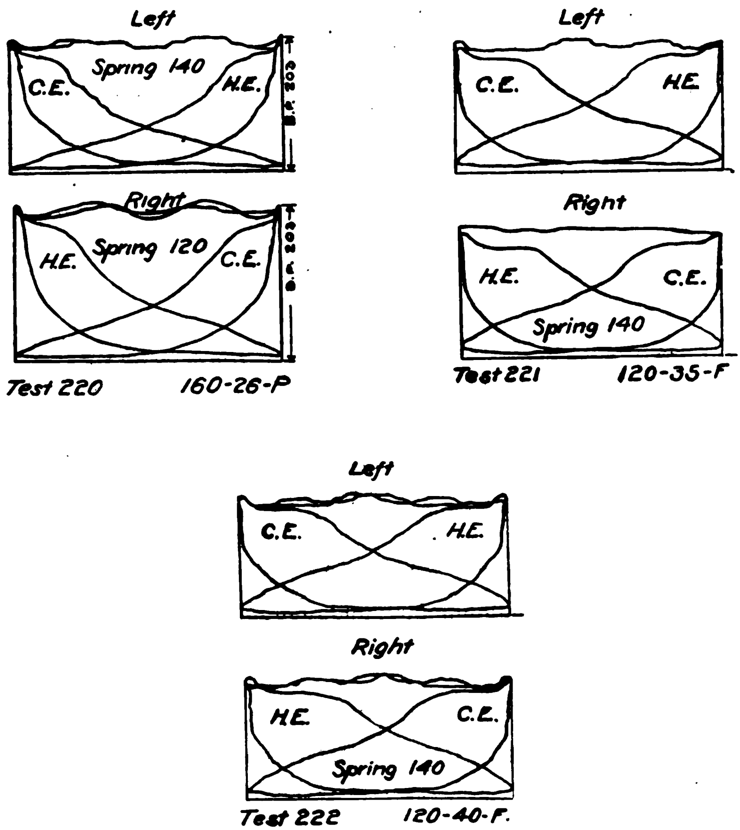
Typical Indicator Diagrams. Locomotive No. 784.



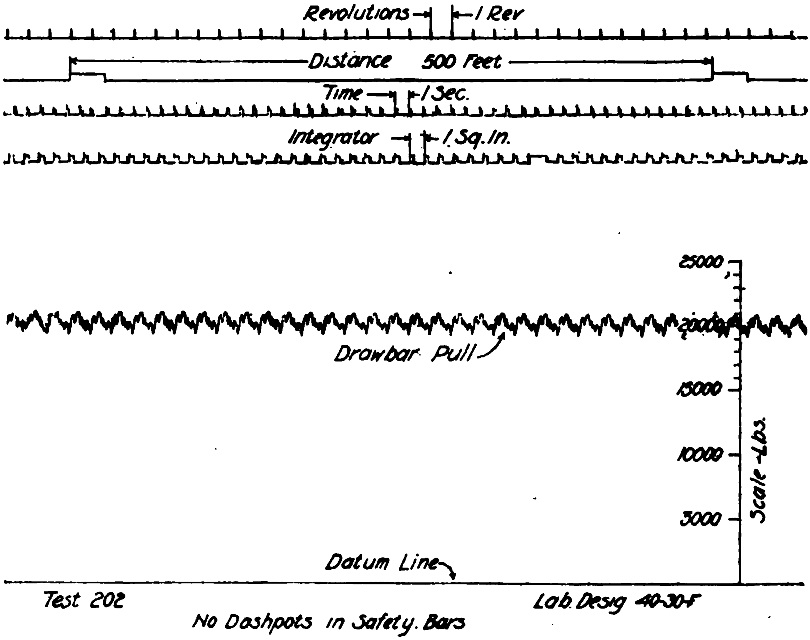
Typical Indicator Diagrams, Locomotive No. 734.



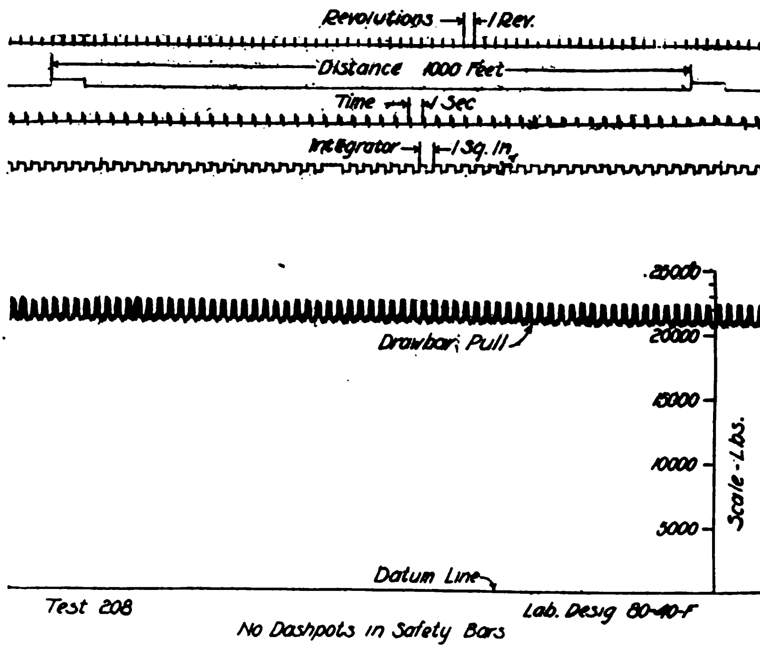
Typical Indicator Diagrams, Locomotive No. 734.



Typical Indicator Diagrams, Locomotive No. 734.

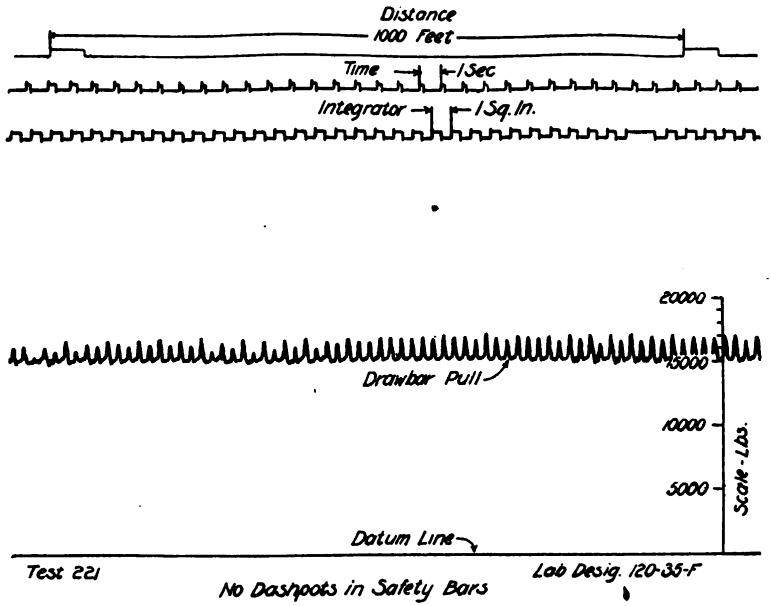


Speed, 7.59 Miles per Hour.

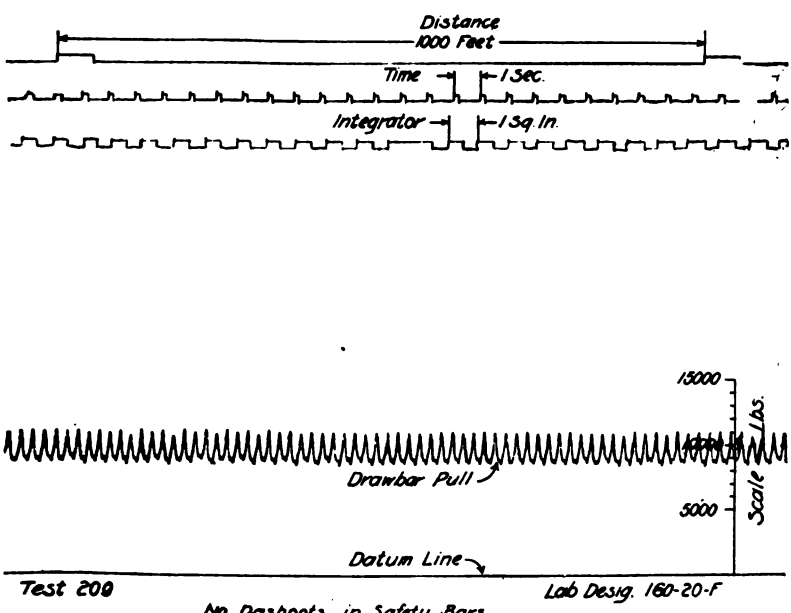


Speed, 14.99 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 734.



Speed, 22.28 Miles per Hour.



Speed, 29.87 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 734.

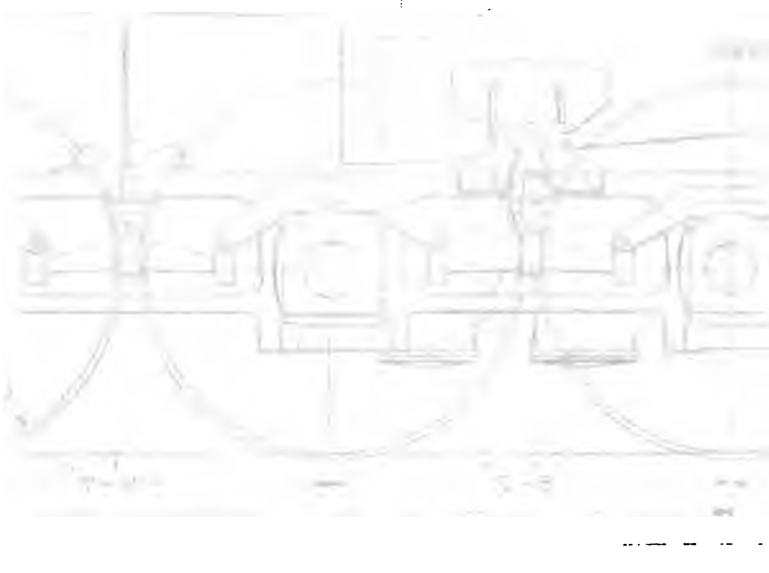


Fig. 212.

CHAPTER XV.

TESTS OF CONSOLIDATION LOCOMOTIVE, MICHIGAN CENTRAL RAILROAD COMPANY.

The third locomotive tested was No. 585, owned by the Michigan Central Railroad Company and built by the American Locomotive Company at its Schenectady Works. It was of the 2-8-0 type and known as class W according to the railroad company's classification. This locomotive was a two-cylinder cross compound.

It was on the plant from August 10 to August 27; work on the dynamometer consuming the time from August 3 to 10. In the twenty-two working days fourteen tests were made, twelve days being lost on account of the plant and three days on account of the locomotive.

The principal dimensions and details of the locomotive are given in Appendix 300. The principal nominal dimensions are shown in the following table:

Total weight, pounds	189,000
Weight on drivers, pounds	164,500
Cylinders (Compound), inches	23 and 35 x 32
Diameter of drivers, inches	63
Fire-box heating surface, square feet	165.69
Heating surface in tubes (water side), square feet	3015.34
Total heating surface (based on water side of tubes), square feet	3181.03
*Total heating surface (based on fire side of tubes), square feet	2819.20
Grate area, square feet	49.43
Boiler pressure, pounds	210

* Used in Calculations.

Valves, High Press., piston; Low Press.,	Allen-Richardson
Link motion	Stephenson
Fire-box, type	Radial stay, wide
Number of tubes	363
Outside diameter of tubes, inches	2
Length of tubes, inches	190.38

The maximum tractive effort was 45,613 pounds working simple and 31,838 pounds working compound. The ratio of weight on drivers to maximum tractive effort when working simple was 3.61:1 and when working compound 5.17:1.

TESTS.

The tests which have been run, together with the laboratory designations and dates of running, are as follows:

TEST NO.	LABORATORY DESIGNATION.	DATE.
301	40-43-F	August 20th.
302	40-45-F	" 20th.
303	40-48-F	" 25th.
305	80-45-F	" 11th.
306	80-42-F	" 13th.
308	80-53-F	" 16th.
309	80-57-F	" 16th.
311	120-51-F	" 22nd.
312	160-47-F	" 23rd.
313	160-50-F	" 17th.
316	160-62-F	" 17th.
317	160-50-P	" 24th.
318	160-61-P	" 27th.
319	160-65-P	" 26th.

The results of test No. 316 have not been plotted owing to

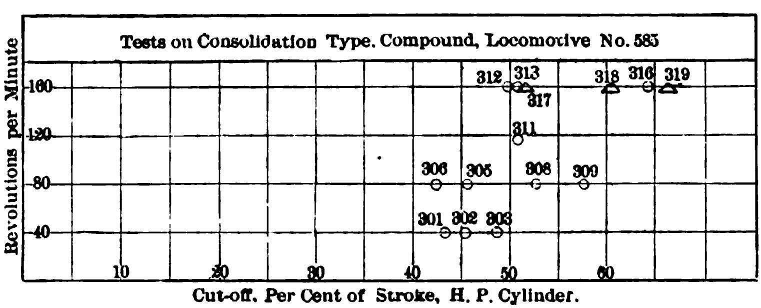


Fig. 301.

its short duration. Test No. 311 was run only to obtain draw-bar pull and horse power at 120 revolutions per minute.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 301.

As in previous chapters, the tests included in the tables in the text are arranged in order according to the rate of equivalent

TABLE No. 301—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
301	40–43–F	180	209.2	14.41	79.5	78.1	63.2
302	40–45–F	180	209.1	14.40	84.6	77.5	62.4
303	40–48–F	180	210.1	14.48	80.4	80.1	65.8
306	80–42–F	180	205.8	14.53	83.0	78.2	103.0
305	80–45–F	180	209.6	14.54	80.1	75.4	108.3
308	80–53–F	180	206.4	14.45	76.8	77.4	127.7
317	160–50–P	109.6	208.7	14.55	70.7	75.2	91.2
312	160–47–F	180	209.0	14.59	75.7	81.6	164.9
309	80–57–F	180	210.9	14.45	83.6	75.9	156.8
318	160–61–P	180	210.7	14.56	67.7	74.4	167.7
319	160–65–P	180	208.3	14.56	75.6	77.8	161.6
313	160–50–F	180	209.3	14.50	81.2	75.8	169.2

evaporation. Of these tests, one was run for 109.6 minutes, while all the rest were of 180 minutes' duration.

The lowest average boiler pressure was 205.8 pounds, while the highest was 210.9 pounds. The temperature of the feed water did not vary more than 7.2 degrees throughout the tests. The total coal fired per square foot of grate area for the several tests, follows:

In 4 tests .... less than 100 pounds.
In 2 tests .... between 100 and 120 pounds.
In 1 test .... between 120 and 150 pounds.
In 5 tests .... between 150 and 200 pounds.

EVAPORATION—TABLE 302.

The evaporation per hour was between the limits of 9,475 pounds and 23,311 pounds.

The quality of steam in the steam dome was high in all of the tests; the moisture never exceeding 1.7 per cent. The rate of evaporation did not apparently affect the quality of the steam in the dome.

TABLE No. 302—EVAPORATION.

Identification of Test		Duration of Test, Minutes	Water and Steam		Calorimeter Results			Equivalent Evaporation Lbs. Per Hour
Test Number	Laboratory Designation		Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Quality of steam in Branch Pipe	Degrees Superheat in Branch Pipe	
		Cal.	284	340	*228	229	230	344
301	40–43–F	180	28426	9475	.9829	.9878	0	11180
302	40–45–F	180	30400	10133	.9831	.9877	0	11966
303	40–48–F	180	32777	10926	.9843	.9874	0	12884
306	80–42–F	180	46248	15416	.9828	.9893	0	18178
305	80–45–F	180	51239	17079	.9828	.9896	0	20205
308	80–53–F	180	57102	19034	.9839	.9894	0	22476
317	160–50–P	109.6	37864	20724	.9841	.9932	0	24538
312	160–47–F	180	63920	21306	.9837	.9914	0	25075
309	80–57–F	180	64636	21545	.9839	.9896	0	25501
318	160–61–P	180	68191	22730	.9838	.9999	0	26864
319	160–65–P	180	69477	23159	.9845	1.0037	6.63	27370
313	160–50–F	180	69932	23311	.9835	.9927	0	27576

The quality of the steam in the branch pipe was slightly higher than that in the steam dome.

BOILER POWER—TABLE 303.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 226 to 558.

The equivalent evaporation per square foot of heating surface ranged from 3.97 to 9.78 pounds per hour.

The maximum boiler horse power developed was 799.3, the horse power being calculated on the usual basis.

The horse power developed per square foot of heating surface ranged from .115 to .284.

The maximum horse power developed per square foot of

TABLE No. 303—BOILER POWER.

Identification of Test		Duration of Test, Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft of Grate Surface
		Cal.	Cal.	345	349	Cal.	Cal.
301	40–43–F	180	226	3.97	324.1	.115	6.56
302	40–45–F	180	242	4.25	346.7	.123	7.01
303	40–48–F	180	261	4.57	373.5	.133	7.56
306	80–42–F	180	368	6.45	526.9	.187	10.66
305	80–45–F	180	409	7.17	585.6	.208	11.85
308	80–53–F	180	455	7.97	651.5	.231	13.18
317	160–50–P	109.6	496	8.70	711.2	.252	14.39
312	160–47–F	180	507	8.89	726.8	.258	14.70
309	80–57–F	180	516	9.05	739.2	.262	14.95
318	160–61–P	180	544	9.53	778.7	.276	15.75
319	160–65–P	180	554	9.71	793.3	.281	16.05
313	160–50–F	180	558	9.78	799.8	.284	16.17

TABLE No. 304—COAL AND RATE OF COMBUSTION.

Identification of Test		Duration of Test, Minutes	Total Dry Coal Fired	Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation			Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq. Ft. of Grate Per Hour	Dry Coal Per Sq. Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
301	40–43–F	180	3081	2891	1027	964	20.78	.364
302	40–45–F	180	3039	2871	1013	957	20.49	.359
303	40–48–F	180	3219	2995	1073	998	21.70	.381
306	80–42–F	180	5049	4707	1683	1569	34.05	.597
305	80–45–F	180	5311	4914	1770	1638	35.81	.628
308	80–53–F	180	6261	5922	2087	1974	42.22	.740
317	160–50–P	109.6	4464	4214	2444	2306	49.44	.867
312	160–47–F	180	8062	7580	2687	2527	54.37	.953
309	80–57–F	180	7677	7281	2559	2427	51.77	.908
318	160–61–P	180	8215	7726	2738	2575	55.40	.971
319	160–65–P	180	7913	7410	2638	2470	53.36	.936
313	160–50–F	180	8300	7792	2767	2597	55.97	.982

grate surface is equivalent to about one horse power for each .062 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 304.

The total dry coal fired ranged from 3,039 pounds to 8,300 pounds, and the amount per hour from 1,013 pounds to 2,767 pounds.

TABLE No. 305—CINDERS AND SPARKS.

Identification of Test		Duration of Test, Minutes	Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation		Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
301	40–43–F	180	59.3	12.7	72.0	12104	9684
302	40–45–F	180	55.0	3.7	58.7	11664	9464
303	40–48–F	180	27.7	4.0	31.7	12104	9684
306	80–42–F	180	45.0	27.3	72.3	12545	10784
305	80–45–F	180	44.0	24.3	68.3	12325	11225
308	80–53–F	180	59.3	30.0	89.3	12545	10564
317	160–50–P	109.6	185.5	54.2	239.7	11884	10344
312	160–47–F	180	106.7	74.0	180.7	11884	10124
309	80–57–F	180	91.0	51.3	142.3	12104	10344
318	160–61–P	180	133.0	83.0	216.0	12325	10344
319	160–65–P	180	96.6	62.3	159.0	12104	10124
313	160–50–F	180	76.3	64.7	141.0	12325	10564

The dry coal fired per square foot of grate area per hour ranged from 20.49 pounds to 55.97 pounds. The increase in the rate of combustion was regular. The maximum consumption of coal per square foot of grate area was very low, but the maximum draft in front of the diaphragm, which it was possible to maintain, was only 3.65 inches of water. The boiler failed when attempts were made to force it to higher rates of combustion.

The coal fired per square foot of heating surface per hour ranged from .359 to .982 pounds.

CINDERS AND SPARKS—TABLE 305.

The maximum calorific value of the cinders was 12,545 B. T. U., and the maximum calorific value of the sparks was 11,225 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 306.

In previous chapters, under this heading, certain relations have been derived. In Chapter XIII the methods employed in obtaining these relations are explained in full. The equations for

TABLE No. 306—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water				Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In front of Diaphragm	Back of Diaphragm	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	223	224	225	212	207	339
301	40–43–F	180	.68	.56	.30	.10	1286	497	20.78
302	40–45–F	180	.74	.61	.28	.09	1429	493	20.49
303	40–48–F	180	.88	.68	.34	.05	1445	508	21.70
306	80–42–F	180	1.43	1.09	.44	.09	1060	519	34.05
305	80–45–F	180	1.95	1.46	.55	.04	1059	563	35.81
308	80–53–F	180	2.37	1.70	.56	.15	1293	570	42.22
317	160–50–P	109.6	2.78	2.17	.84	.09	1739	609	49.44
312	160–47–F	180	2.74	2.04	.95	.09	1617	615	54.37
309	80–57–F	180	3.19	2.22	.64	.15	1332	592	51.77
318	160–61–P	180	3.38	2.42	.95	.13	1573	622	55.40
319	160–65–P	180	3.56	2.54	1.07	.16	1264	616	53.36
313	160–50–F	180	3.65	2.52	1.01	.14	1488	587	55.97

this locomotive are, therefore, merely enumerated below without repeating a description of the mathematical processes:

$$D = .058G \qquad (301)$$

$$T_f = 2.91\,G + 1320 \qquad (302)$$

$$T_s = 2.77G + 440 \qquad (303)$$

$$T_f - T_s = .14G + 880 \qquad (304)$$

$$H = .141G + 1.6 \qquad (305)$$

$$G = 7.14\,(T_f - T_s) - 6286 \qquad (306)$$

$$G = 7.09\,H - 11.3 \qquad (307)$$

$$H = 1.007\,(T_f - T_s) - 884.7 \qquad (308)$$

The fire-box temperatures ranged from 1,059 to 1,739 degrees Fahr. The difference in temperature between the fire-box and smoke-box was nearly constant for all rates of combustion.

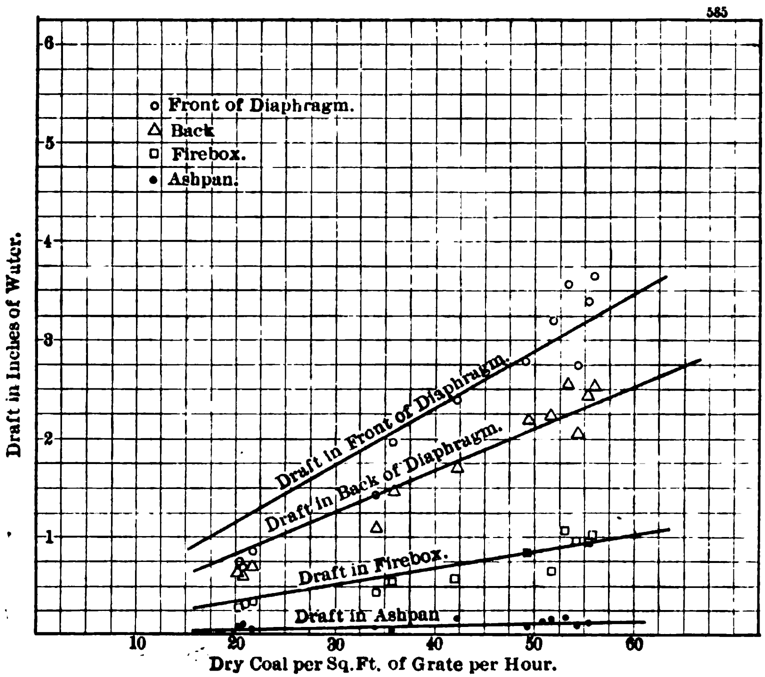


Fig. 302.— Draft and Rate of Combustion.

EVAPORATIVE PERFORMANCE—TABLE 307.

The equivalent evaporation per pound of dry coal ranged from 12.01 pounds to 9.24 pounds.

The heating value of the coal was practically uniform for all the tests.

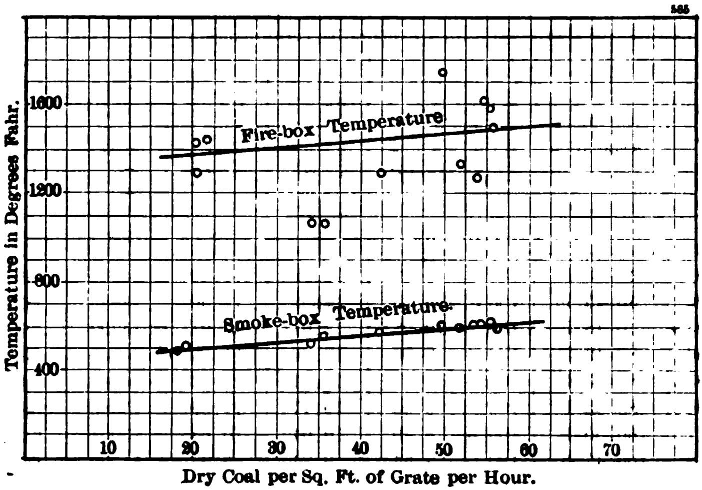


Fig. 303.— Fire Box and Smoke Box Temperatures.

The efficiency of this boiler between the lowest and highest rates of evaporation, decreased as the rate of evaporation increased and ranged from 78.42 per cent. to 60.41 per cent.

From Fig. 305, the relation between H and E is:

$$E = 13.35 - .357\ H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (309)$$

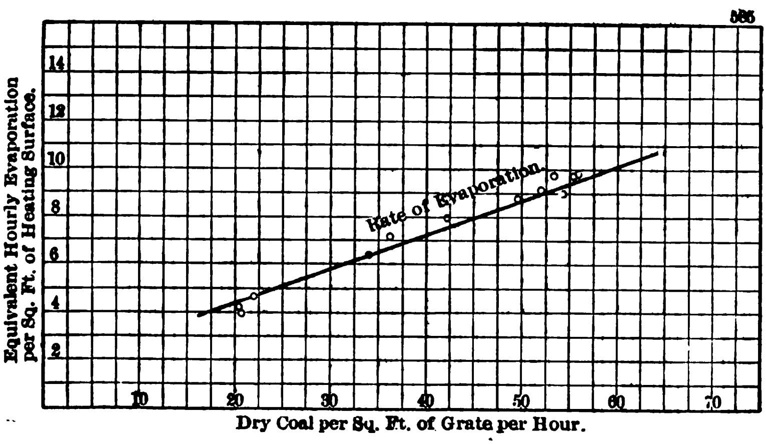


Fig. 304.— Rates of Combustion and Evaporation.

TABLE No. 307—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
301	40–43–F	180	9.10	10.89	11.60	14946	70.34
302	40–45–F	180	9.85	11.82	12.50	14843	76.88
303	40–48–F	180	10.08	12.01	12.91	14792	78.42
306	80–42–F	180	9.08	10.80	11.59	14840	70.29
305	80–45–F	180	9.57	11.41	12.33	14863	74.16
308	80–53–F	180	9.05	10.77	11.39	15083	68.96
317	160–50–P	109.6	8.40	10.04	10.64	15004	64.62
312	160–47–F	180	7.84	9.24	9.92	14799	60.41
309	80–57–F	180	8.34	9.97	10.56	15003	64.18
318	160–61–P	180	8.23	9.81	10.43	14990	63.21
319	160–65–P	180	8.70	10.38	11.08	14888	67.33
313	160–50–F	180	8.36	9.97	10.62	14966	64.32

TABLE No. 308—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
301	40–43–F	180	9.13	.0	10.47	80.40	14746	.0
302	40–45–F	180	7.67	.13	10.13	82.07	14636	.74
303	40–48–F	180	9.53	.10	9.80	80.57	14636	.59
306	80–42–F	180	3.87	.83	13.70	81.60	14746	3.31
305	80–45–F	180	5.57	.17	13.53	80.73	14746	.72
308	80–53–F	180	4.53	.30	13.80	81.37	14966	1.22
317	160–50–P	109.6	8.70	.15	10.50	80.65	14856	.81
312	160–47–F	180	5.67	.30	12.57	81.46	14636	1.36
309	80–57–F	180	4.63	.20	13.37	81.80	14856	.85
318	160–61–P	180	4.64	.70	13.03	81.63	14856	2.93
319	160–65–P	180	5.87	.23	12.57	81.33	14846	1.04
313	160–50–F	180	5.93	.10	13.27	80.70	14856	.43

SMOKE-BOX GASES—TABLE 308.

While the percentage of oxygen showed some irregularities, nevertheless there was a tendency for it to decrease as the rate of evaporation increased—the range for the several tests being between the limits of 9.53 per cent. and 3.87 per cent.

The percentage of CO did not increase uniformly as the rate of evaporation increased—the range for this locomotive being between the limits of .0 per cent. and .83 per cent.

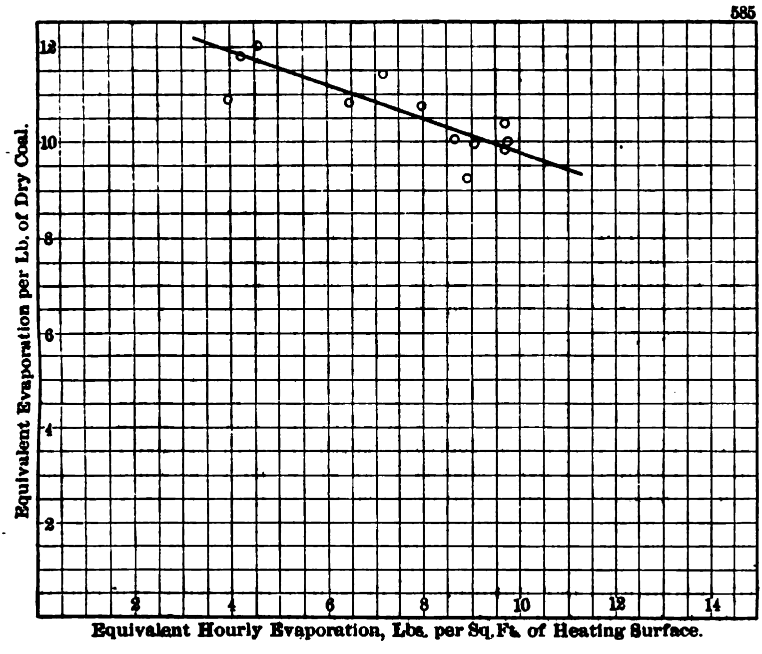


Fig. 305.—Rate of Evaporation and Evaporation per Lb. of Coal.

The carbon dioxide, CO_2, ranged from 9.8 per cent. to 13.8 per cent.

The heat lost by imperfect combustion ranged from 0.0 to 3.31 per cent.

PERFORMANCE OF ENGINES.

The arrangement of results in Tables 309 and 310 has been explained in Chapter XIII. The tests at each speed are arranged with reference to the nominal cut-off in the high pressure cylinder.

GENERAL ENGINE CONDITIONS—TABLE 309.

The lowest speed at which any test was run was 7.49 miles per hour and the highest 29.97 miles per hour. Higher speeds were not attempted on account of the severe longitudinal vibration of the locomotive. The critical speed, however, was found to be

TABLE No. 309—GENERAL ENGINE CONDITIONS.

Identification of Test		Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke	Steam Pressure	
Test Number	Laboratory Designation					In Boiler Lbs. Per Sq. In.	In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	217	220
301	40–43–F	180	40.00	7.49	43.1	209.2	204.3
302	40–45–F	180	39.99	7.49	45.8	209.1	204.0
303	40–48–F	180	40.01	7.49	48.6	210.1	208.5
306	80–42–F	180	80.18	15.01	42.2	205.8	202.0
305	80–45–F	180	79.86	14.96	45.7	209.6	204.7
308	80–53–F	180	80.00	14.98	52.8	206.4	203.9
309	80–57–F	180	79.98	14.98	57.5	210.9	210.9
312	160–47–F	180	160.02	29.97	49.6	209.0	202.7
313	160–50–F	180	160.01	29.97	50.7	209.3	207.7
317	160–50–P	109.6	159.95	29.96	51.5	208.7	177.0
318	160–61–P	180	160.03	29.97	60.8	210.7	160.5
319	160–65–P	180	160.01	29.97	66.0	208.3	136.5

167 revolutions per minute. The safety bars were not equipped with dash-pots during the testing of this locomotive.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 310.

As in Chapter XIII, the relations between the mean effective pressure, the total indicated horse power and the steam consumption, for the several high pressure cut-offs and speeds is shown by Figs. 306, 307, and 308.

The lower figure in each rectangle of Figs. 306 and 308 refers to the low pressure cylinder and the upper figure to the high pressure cylinder.

The best performance of the engines was at 45.7 per cent. high pressure cut-off and 79.86 revolutions per minute (about 15

TABLE No. 310—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch: H. P. Cyl.	Mean Effective Pressure Lbs. Per Sq. Inch: L. P. Cyl.	Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
		Cal.	Cal.	Cal.	379	381
301	40-43-F	180	66.03	42.76	442.5	20.20
302	40-45-F	180	74.07	44.94	477.4	20.09
303	40-48-F	180	81.12	47.44	512.0	20.27
306	80-42-F	180	62.18	32.23	734.9	20.15
305	80-45-F	180	69.04	38.03	840.6	19.54
308	80-53-F	180	78.94	41.03	932.2	19.69
309	80-57-F	180	90.09	44.98	1040.7	20.03
312	160-47-F	180	36.64	20.05	890.1	23.18
313	160-50-F	180	41.79	21.92	991.6	22.80
317	160-50-P	109.6	37.61	20.47	910.4	21.98
318	160-61-P	180	42.54	19.43	937.7	23.56
319	160-65-P	180	43.01	19.09	934.2	24.14

TABLE No. 311—DYNAMOMETER RECORDS.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D.H.P. Hour
		Cal.	265	383	384	385
301	40-43-F	180	20605	411.5	2.38	21.72
302	40-45-F	180	22149	442.2	2.19	21.69
303	40-48-F	180	24105	481.6	2.14	21.55
306	80-42-F	180	16879	675.7	2.42	21.92
305	80-45-F	180	19393	773.3	2.23	21.24
308	80-53-F	180	21815	871.4	2.34	21.06
309	80-57-F	180	24539	980.0	2.56	21.27
312	160-47-F	180	9138	730.1	3.61	28.27
313	160-50-F	180	10308	823.6	3.30	27.45
317	160-50-P	109.6	9102	727.0	3.28	27.52
318	160-61-P	180	9530	761.4	3.54	29.01
319	160-65-P	180	9236	737.9	3.52	30.56

miles per hour), under which conditions the steam consumption was 19.54 pounds of dry steam per indicated horse power hour. At full throttle tests the steam per indicated horse power ranged from 19.54 to 23.18 pounds.

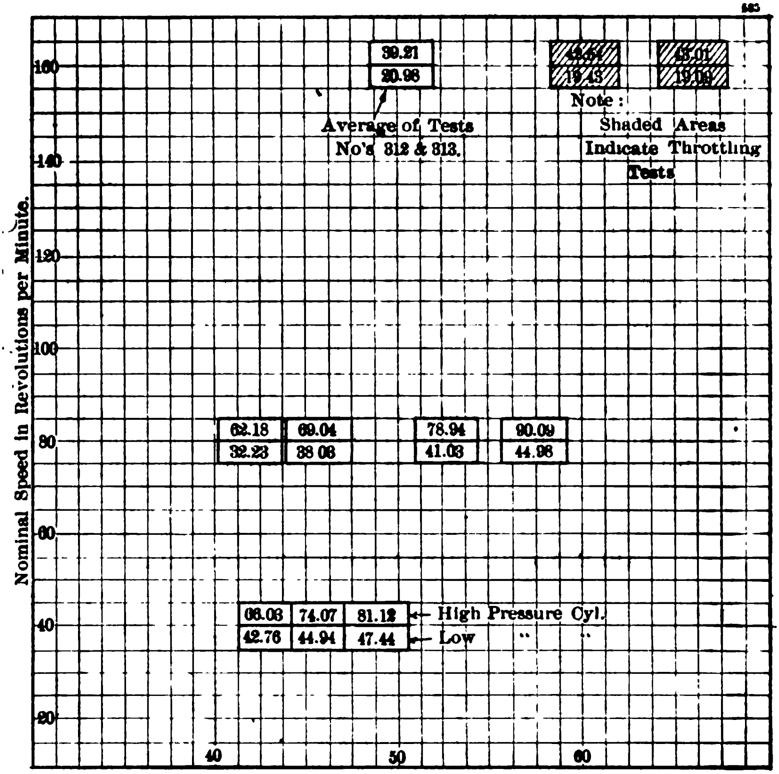


Fig. 306.— Mean Effective Pressure.

The highest indicated horse power was 1040.7, which was obtained at 57.5 per cent high pressure cut-off and a speed of 79.98 revolutions per minute.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 311.

The maximum average recorded draw-bar pull was 24,539 pounds at a nominal speed of 80 revolutions per minute and a high pressure cut-off of 57.5 per cent. Higher draw-bar pulls were not obtained because at slow speeds and long cut-offs there was constant danger of stalling the brakes and slipping the drivers, owing to the fluctuations of the water pressure.

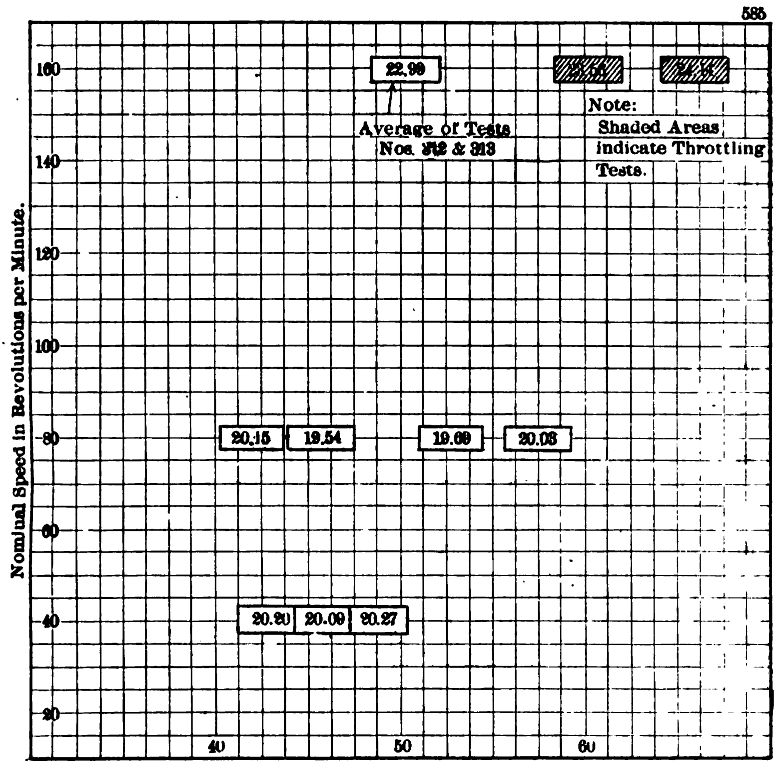


Fig. 307.—Dry Steam per I. H. P. Hour.

The maximum dynamometer horse power was 980.0, which was obtained at a nominal speed of 80 revolutions per minute and a high pressure cut-off of 57.5 per cent.

The minimum dry coal rate obtained was 2.14 pounds, and the maximum rate 3.61 pounds per dynamometer horse power hour.

The lowest steam consumption was 21.06 pounds of dry steam per dynamometer horse power hour, which was obtained at a nominal speed of 80 revolutions per minute and a high pressure cut-off of 52.8 per cent.

MACHINE FRICTION—TABLE 312.

The friction of the mechanism of the locomotive is given in terms of horse power and draw-bar pull.

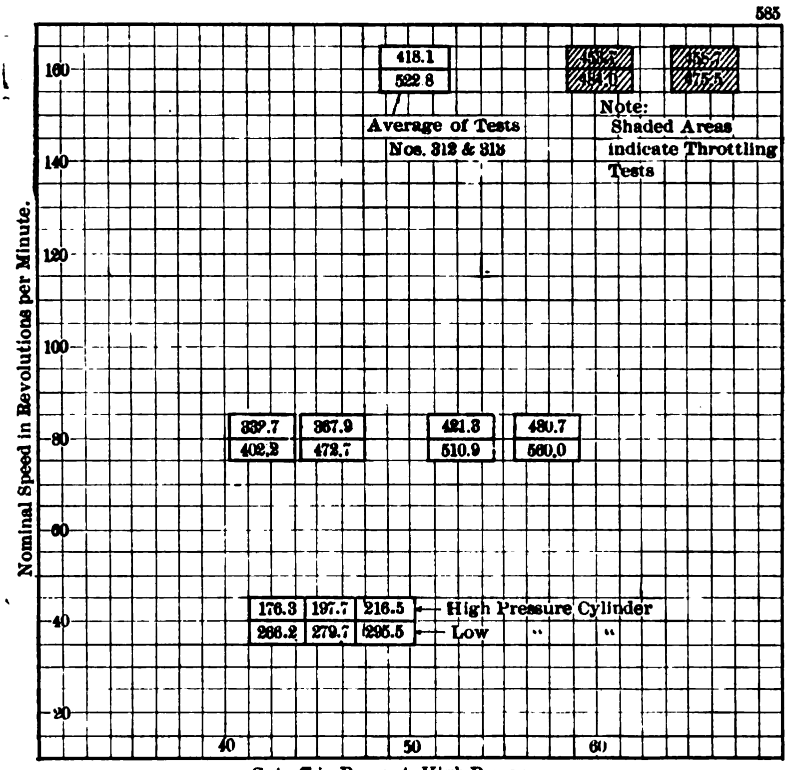


Fig. 308.— Total Indicated Horse Power.

The machine efficiency was uniformly high and ranged from 78.98 per cent. to 94.16 per cent.

MAXIMUM POWER OF LOCOMOTIVE.

It is impossible from the recorded data to construct directly for this locomotive a diagram showing the maximum draw-bar pull at all speeds. The maximum evaporative power of the boiler, as disclosed by these tests, is between 23,000 and 24,000 pounds of steam per hour. By applying the method explained in Chapter XIII, page 143, the maximum draw-bar pull of the locomotive as limited by the adhesive weight and the maximum evaporative power of this boiler, has been obtained.

TABLE No. 312—MACHINE FRICTION.

Identification of Test		Duration of Test, Minutes	Machine Friction in		Machine Efficiency Per Cent.
Test Number	Laboratory Designation		Horse Power	Draw-Bar Pull Pounds	
		Cal.	395	397	398
301	40–43–F	180	30.98	1551	93.00
302	40–45–F	180	35.22	1764	92.63
303	40–48–F	180	30.43	1523	94.06
	Average		32.21	1613	
306	80–42–F	180	59.21	1478	91.95
305	80–45–F	180	67.33	1686	91.99
308	80–53–F	180	60.80	1522	93.48
309	80–57–F	180	60.71	1520	94.16
	Average		62.01	1552	
312	160–47–F	180	160.02	2008	82.02
313	160–50–F	180	168.02	2103	83.05
317	160–50–P	109.6	183.35	2296	79.89
318	160–61–P	180	176.26	2206	81.20
319	160–65–P	180	196.32	2457	78.98
	Average		176.79	2213	

The critical cut-off, the steam consumption and the maximum cylinder horse power, for the several speeds, as disclosed by Figs. 309 and 310, are shown in the following table:

NOMINAL SPEED IN R.P.M.	HIGH PRESSURE CUT-OFF IN PER CENT.	STEAM PER INDICATED HORSE POWER HOUR.	MAXIMUM CYLINDER HORSE POWER.
40	83	29	795
80	63	21	1100
160	54	23	1020

Reducing the maximum cylinder horse power to equivalent

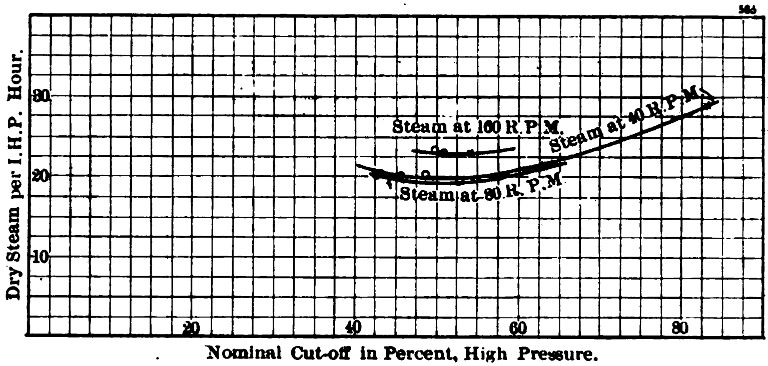


Fig. 309.— Steam Consumption.

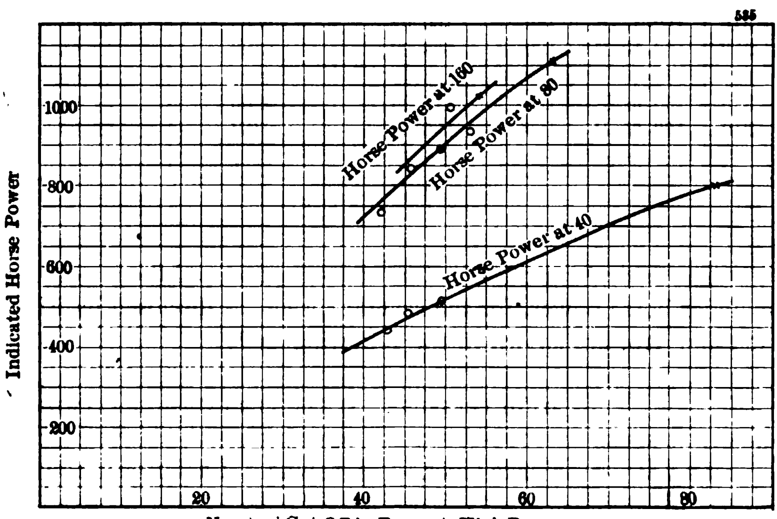


Fig. 310.— Indicated Horse Power.

draw-bar pull and subtracting the average frictional draw-bar pull gives:

SPEEDS IN R.P.M.	MAXIMUM ESTIMATED DRAW-BAR PULL POUNDS.
40	38190
80	26000
160	10537

The diagram, Fig. 311, shows that the lowest speed at which the full power of the boiler can be utilized, when working

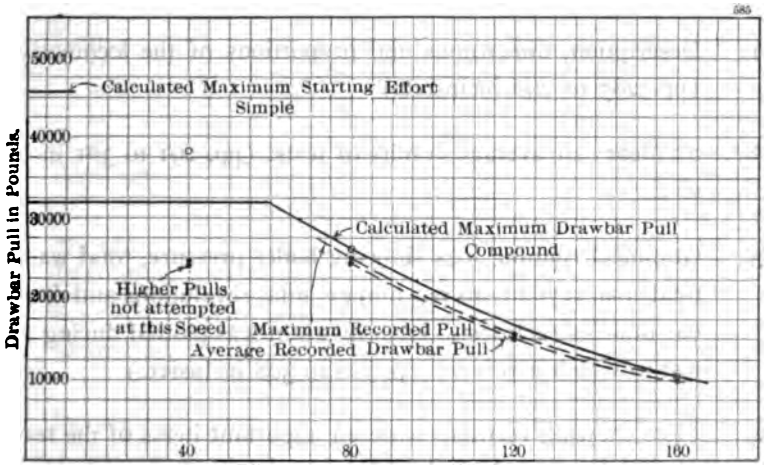


Fig. 311.—Maximum Draw-bar Pull.

compound, was about 60 revolutions per minute. At 160 revolutions per minute the maximum recorded pull and the maximum calculated pull coincide.

APPENDIX 800.

The appendix contains:

1. Description, dimensions and proportions of the locomotive. (pp. 285 to 290 inclusive.)

2. Summary of average results of tests. (pp. 291 to 301 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 302 to 308 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 309 to 324 inclusive.)

5. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 325 to 327 inclusive.)

6. A typical dynamometer diagram for each nominal speed. (pp. 328 and 329.)

7. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of Michigan Central W Consolidation (2-8-0) Type Locomotive No. 585.

Built by the American Locomotive Co., Schenectady, N. Y., January, 1902.

DRIVING WHEELS.

1	Number of pairs	4
2	Approximate diameter, inches	63

MEASURED CIRCUMFERENCE, FEET.

3	Right, No. 1	16.47
4	" " 2	16.48
5	" " 3	16.49
6	" " 4	16.48
7	" " 5	——
8	Left, " 1	16.48
9	" " 2	16.49
10	" " 3	16.50
11	" " 4	16.48
12	" " 5	——
13	Average	16.48

ENGINE TRUCK WHEELS.

14	Number	2
15	Diameter, inches	33

TRAILING WHEELS.

16	Diameter, inches	——

WHEEL BASE, FEET.

17	Driving wheel base	16.99
18	Total wheel base	25.79
19	Gauge of wheels, in inches	56.00

WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.

20	On truck	24,500
21	" 1st drivers	44,200
22	" 2nd "	44,800
23	" 3rd "	39,800
24	" 4th "	35,700
25	" 5th "	——
26	" trailers	——
27	Total	189,000
28	" on drivers	164,500

CYLINDERS.

29	High pressure, number	1
30	Low " "	1
31	Arrangement	outside, cross compound

DIAMETER, INCHES.

32	High pressure, right	——
33	" " left	23.096
34	Low " right	35.106
35	" " left	——

STROKE OF PISTON, FEET.

36	High pressure, right	——
37	" " left	2.667
38	Low " right	2.671
39	" " left	——

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P., right, head end	——
41	" " crank "	——
42	" left, head "	17.09
43	" " crank "	16.28
44	L. P., right, head "	5.76
45	" " crank "	5.66
46	" left, head "	——
47	" " crank "	——

RECEIVER, CUBIC FEET.

48	Volume, right side	19.0
49	" left "	

STEAM PORTS, INCHES.

(For piston valves the length equals the circumference of inside of bushing, minus the sum of the widths of bridges.)

50	H. P. admission, right, head end, length	——
51	" " " " " width	——
52	" " " crank " length	——
53	" " " " " width	——
54	" " left, head " length	34.70
55	" " " " " width	2.13
56	" " " crank " length	34.63
57	" " " " " width	2.13
58	L. P. " right, head " length	22.72
59	" " " " " width	2.11
60	" " " crank " length	22.78
61	" " " " " width	2.11
62	" " left, head " length	——
63	" " " " " width	——
64	" " " crank " length	——
65	" " " " " width	——
66	H. P. exhaust, right, length	——
67	" " " width	——
68	" " left, length	44.05
69	" " " width	13.06
70	L. P. " right. length	22.74

71	L. P. exhaust, right, width	2.98
72	" " left, length	——
73	" " " width	——

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	——
75	" " left	3.998
76	Low " right	4.022
77	" " left	——

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	" " left	——
80	Low " right	——
81	" " left	——

VALVES.

82	Type	H. P., "piston"; L. P., "D" slide
83	Design	H. P., outside adm.; L. P., Allen-Richardson
84	Per cent. of balanced to total area	H.P. 90.63, L.P. 57.88
85	Type of link motion	Stephenson, open rods

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	——
87	" " left	5.625
88	Low " right	5.687
89	" " left	——

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure right, head end	——
91	" " " crank "	——
92	" " left, head "	1.186
93	" " " crank "	1.186
94	Low " right, head "	.995
95	" " " crank "	.995
96	" " left, head "	——
97	" " " crank "	——

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,		——
99	" " " crank "		——
100	" " left, head "	negative	.107
101	" " " crank "	"	.102
102	Low " right, head "	"	.23
103	" " " crank "	"	.23
104	" " left, head "		——
105	" " " crank "		——

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	sheet steel
108	Lead, forward motion,	H. P. none, L. P. .031
109		
110		
111	Area of Allen Port,	L. P. Valve, sq. in. 13.95
112	Right crank leads.	

BOILER.

113	Type	Straight top, wide fire box
114	Outside diameter, 1st ring, inches	70.125

TUBES.

115	Number	363.
116	Outside diameter, inches	2.
117	Thickness, inches	.12
118	Length between tube sheets, inches	190.375
119	Total fire area, square feet	6.13
120	Serve tubes, number of ribs	——
121	" " sq. in, of inside surface in one in. of length	——
122		
123		
124	Boiler pressure, pounds per sq. in.	210

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129		
130		
131		

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	92.4
133	Width	66.6
134	Depth, front end	65.4
135	" back "	54.0
136	Volume, cubic feet (less arch and tubes)	177.88
137	Air inlets to ash pan, dampers closed, sq. ft.	2.94
138	" " " " " " open, " "	7.98
139		
140		

FIRE DOORS.

141	Number	2
142	Area square feet	2.45
143		

GRATES.

144	Style	rocking
145	Total area, square feet	49.43
146	" " dead grates, square feet	0.0
147	Width of air spaces, inches	.75

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	0.
149	" grates	17.02
150	" fire doors	.08
151	Total air inlets (148) (149) and (150)	17.10
152	Ratio " " (149) to grate area (145)	.344
153	" " " (151) " " " (145)	.345

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	3015.34
155	" " " fire "	2653.51
156	" " firebox, fire side, including arch tubes	165.69
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	2819.20
159	Total, based on inside of firebox and outside of tubes	3181.03

BOILER VOLUMES.

(With water surface at level of second gauge cock.)

160	Water space, cubic feet	301.83
161	Steam " " "	71.37

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	5.5
164	" " left, "	
165	Area of right, square inches	——
166	" " left, " "	——
167	Total area, square inches	23.76

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	18
169	L. P. " " " " "	
170	Nine notches blank from center to eighteenth notch.	

RATIOS.

171	Heating surface (158) to grate area (145)......	57.03
172	Fire area through tubes (119) to grate area (145)	.124
173	Firebox heating surface (156) to grate area (145)	3.35
174	Tube surface (155) to firebox heating surface (156)..................................	16.01
175	Firebox volume (136) to grate area (145)......	3.599
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(*power developed at one R. P. M. when pull is one pound.*)

179	....	.0004993

CONSTANTS FOR INDICATED HORSE POWER

(*power developed at one R. P. M. and one pound M. E. P.*)

180	High	pressure	cylinder,	right,	head end	....	——
181	"	"	"	"	crank "	....	——
182	"	"	"	left,	head "	....	.03387
183	"	"	"	"	crank "	....	.03285
184	Low	"	"	right,	head "	....	.07834
185	"	"	"	"	crank "	....	.07731
186	"	"	"	left,	head "	....	——
187	"	"	"	"	crank "	....	——

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head end	....	——
189	"	"	"	"	crank "	....	——
190	"	"	"	left,	head "	....	7.761
191	"	"	"	"	crank "	....	7.528
192	Low	"	"	right,	head "	....	17.954
193	"	"	"	"	crank "	....	17.718
194	"	"	"	left,	head "	....	——
195	"	"	"	"	crank "	....	——

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

MICHIGAN CENTRAL RAILROAD COMPANY.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed: Revolutions: Total	Speed: Revolutions: Average Per Minute	Speed: Equivalent: Speed in Miles Per Hour	Speed: Equivalent: Piston Speed in Feet Per Minute	Position of Levers: Reverse, Notches From Front End	Position of Levers: Tests marked thus * not plotted	Position of Levers: Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	
		196	197	198	199	200	201	202	203	204	205
301	40–43–F	3.00	7200	40.00	7.49	213.5	19		FULL	46	
302	40–45–F	3.00	7198	39.99	7.49	213.5	18		"	43	
303	40–48–F	3.00	7202	40.01	7.49	213.6	17		"	43	
305	80–45–F	3.00	14375	79.86	14.96	426.3	18		"	47	
306	80–42–F	3.00	14432	80.18	15.01	428.0	19		"	46	
308	80–53–F	3.00	14400	80.00	14.98	427.1	16		"	50	
309	80–57–F	3.00	14397	79.98	14.98	426.9	14		"	55	
311	120–51–F	.50	3538	117.93	22.09	629.6	18		"		
312	160–47–F	3.00	28803	160.02	29.97	854.3	19		"	55	
313	160–50–F	3.00	28802	160.01	29.97	854.3	18		"	51	
316	160–62–F	1.50	14397	159.97	29.96	854.1	15	*	"	56	
317	160–50–P	1.83	17528	159.95	29.96	853.9	18		19	58	
318	160–61–P	3.00	28805	160.03	29.97	854.3	16		17	46	
319	160–65–P	3.00	28802	160.01	29.97	854.3	14		19	41	

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of: Smoke Box: By Thermometer	Smoke Box: By Pyrometer	Laboratory: Dry Bulb	Laboratory: Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer				Steam lost from Boiler, etc. Lbs. per hour
		206	207	208	209	210	211	212	213	214	215	216
301	40–43–F	454	497	79.5	75.3	389.3	78.1	1286				423
302	40–45–F	464	493	84.6	77.7	389.2	77.5	1429				423
303	40–48–F	—	508	80.4	72.4	391.0	80.1	1445				428
305	80–45–F	564	563	80.1	69.9	389.6	75.4	1059				448
306	80–42–F	587	519	83.0	74.7	388.5	78.2	1060				419
308	80–53–F	579	570	76.8	69.4	389.2	77.4	1293				451
309	80–57–F	563	592	83.6	72.1	391.9	75.9	1332				458
311	120–51–F											
312	160–47–F	632	615	75.7	63.1	388.8	81.6	1617				423
313	160–50–F	616	587	81.3	73.5	390.7	75.8	1488				427
316	160–62–F	618	638	86.1	74.8	378.4	76.3	1620				357
317	160–50–P	—	609	70.7	64.8	378.1	75.2	1739				483
318	160–61–P	—	622	67.7	60.1	370.6	74.4	1573				381
319	160–65–P	—	616	75.6	63.4	358.8	77.8	1264				354

For date of test, see item 407.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

MICHIGAN CENTRAL RAILROAD COMPANY.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	In Boiler: Maximum	In Boiler: Minimum	In Branch Pipe	Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box: Front of Diaphragm.	In Smoke Box: Back of Diaphragm.	In Fire Box	In Ash Pan	Injectors: Hours in Action: Total, Right	Hours in Action: Total, Left
		217	218	219	220	221	222	223	224	225	226	227
301	40-43-F	209.2	211.1	207.1	204.3	14.41	.68	.56	.30	.10	0	1.71
302	40-45-F	209.1	212.2	201.2	204.0	14.40	.74	.61	.28	.09	0	1.74
303	40-48-F	210.1	212.3	205.5	208.5	14.48	.88	.68	.34	.05	0	1.67
305	80-45-F	209.6	218.5	202.5	204.7	14.54	1.95	1.46	.55	.04	0	2.96
306	80-42-F	205.8	214.5	196.2	202.0	14.58	1.43	1.09	.44	.09	0	2.66
308	80-53-F	206.4	211.5	200.5	203.9	14.45	2.87	1.70	.56	.15	0	3.00
309	80-57-F	210.9	214.2	200.5	210.9	14.45	3.19	2.22	.64	.15	0	3.00
311	120-51-F	209.6					2.81	2.08	.74	.08	0	.48
312	160-47-F	209.0	211.8	205.3	202.7	14.59	2.74	2.04	.95	.09	0	3.00
313	160-50-F	209.3	212.5	204.5	207.7	14.50	3.65	2.52	1.01	.14	0	3.00
316	160-62-F	175.1	197.4	157.5	169.4	14.51	5.02	3.94	1.60	.19	0	1.50
317	160-50-P	208.7	214.9	203.2	177.0	14.55	2.78	2.17	.84	.09	0	1.81
318	160-61-P	210.7	213.0	213.0	160.5	14.56	3.38	2.42	.95	.13	0	2.96
319	160-65-P	208.3	210.7	203.0	186.5	14.56	3.56	2.54	1.07	.16	0	2.97

Test Number	Laboratory Designation	Quality of steam: In Dome	In Branch Pipe	Degrees of Superheat in Branch Pipe	Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Coal Fired: Kind	Coal Fired: Total	Coal Fired: Per Cent of Moisture	Total: Dry Coal Fired	Total: Combustible by Analysis	Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
301	40-43-F	.9829	.9878	0	.98761	Bituminous	3125	1.40	3081	2891	190
302	40-45-F	.9831	.9877	0	.98776	"	3085	1.45	3039	2871	167
303	40-48-F	.9843	.9874	0	.98860	"	3253	1.06	3219	2995	224
305	80-45-F	.9828	.9896	0	.98760	"	5353	.79	5311	4914	396
306	80-42-F	.9828	.9893	0	.98750	"	5092	.84	5049	4707	342
308	80-53-F	.9839	.9894	0	.98830	"	6310	.78	6261	5922	339
309	80-57-F	.9839	.9896	0	.98855	"	7753	.98	7677	7281	435
311	120-51-F										
312	160-47-F	.9837	.9914	0	.98820	"	8152	1.10	8062	7580	483
313	160-50-F	.9835	.9927	0	.98805	"	8362	.74	8300	7792	506
316	160-62-F	.9877	.9965	0	.99095	"	5858	.75	5814	5457	357
317	160-50-P	.9841	.9932	0	.98850	"	4510	.99	4464	4214	251
318	160-61-P	.9838	.9999	0	.98853	"	8290	.90	8215	7726	489
319	160-65-P	.9845	1.0037	6.63	.98880	"	7990	.96	7913	7410	503

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

Michigan Central Railroad Company.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs. Total: Cinders Collected in Smoke Box	Coal, Sparks and Ash, Lbs. Total: Sparks Discharged From Stack	Coal, Sparks and Ash, Lbs. Total: Cinders and Sparks	Analysis of Coal, Per Cent: Fixed Carbon	Analysis of Coal, Per Cent: Volatile Matter	Analysis of Coal, Per Cent: Moisture	Analysis of Coal, Per Cent: Ash	Analysis of Coal, Per Cent: Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
301	40–43–F	178	38	216	75.84	16.67	1.40	6.09	.76		
302	40–45–F	165	11	176	76.20	16.93	1.45	5.42	.86		
303	40–48–F	83	12	95	74.82	17.25	1.06	6.87	1.17		
305	80–45–F	132	73	205	75.18	16.63	.79	7.40	1.99		
306	80–42–F	135	82	217	75.38	17.06	.84	6.72	1.28		
308	80–53–F	178	90	268	76.80	17.05	.78	5.87	.69		
309	80–57–F	273	154	427	76.10	17.31	.98	5.61	.80		
311	120–51–F										
312	160–47–F	320	222	542	75.80	17.28	1.10	5.92	1.21		
313	160–50–F	229	194	423	76.02	17.17	.74	6.07	.78		
316	160–62–F	602	154	756	76.08	17.07	.75	6.10	.81		
317	160–50–P	339	99	438	76.16	17.28	.99	5.57	1.07		
318	160–61–P	399	249	648	75.71	17.49	.90	5.90	1.04		
319	160–65–P	290	187	477	75.14	17.60	.96	6.30	1.23		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B. T. U.: Of Dry Coal	Calorific Value Per Lb. of Fuel, B. T. U.: Of Combustible	Calorific Value Per Lb. of Fuel, B. T. U.: Of Cinders	Calorific Value Per Lb. of Fuel, B. T. U.: Of Sparks		Analysis of Smoke Box Gases, Per Cent: Oxygen O	Analysis of Smoke Box Gases, Per Cent: Carbon Monoxide CO	Analysis of Smoke Box Gases, Per Cent: Carbon Dioxide CO_2	Analysis of Smoke Box Gases, Per Cent: Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
301	40–43–F	14946	15939	12104	9684		9.13	.00	10.47	80.40		
302	40–45–F	14843	15715	11664	9464		7.67	.13	10.13	82.07		
303	40–48–F	14792	15896	12104	9684		9.53	.10	9.80	80.57		
305	80–45–F	14863	16061	12325	11225		5.57	.17	13.53	80.73		
306	80–42–F	14840	15952	12545	10784		3.87	.83	13.70	81.60		
308	80–53–F	15083	15947	12545	10564		4.53	.30	13.80	81.37		
309	80–57–F	15003	15904	12104	10344		4.63	.20	13.37	81.80		
311	120–51–F											
312	160–47–F	14799	15740	11884	10124		5.67	.30	12.57	81.46		
313	160–50–F	14966	15958	12325	10564		5.93	.10	13.27	80.70		
316	160–62–F	14857	15830	11884	11004		2.30	2.05	13.55	82.10		
317	160–50–P	15004	15899	11884	10344		8.70	.15	10.50	80.65		
318	160–61–P	14990	15939	12325	10344		4.64	.70	13.03	81.63		
319	160–65–P	14888	15900	12104	10124		5.87	.23	12.57	81.33		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

MICHIGAN CENTRAL RAILROAD COMPANY.

Test Number	Laboratory Designation	Water, in Pounds: Delivered to Injectors	Water, in Pounds: Lost: From Boiler	Water, in Pounds: Lost: From Injectors	Water, in Pounds: Lost: From	Water, in Pounds: Lost: Total	Water, in Pounds: Delivered to Boiler and Presumably Evaporated	Dynamometer: Drawbar Pull in Pounds: Average	Dynamometer: Drawbar Pull in Pounds: Maximum	Dynamometer: Drawbar Pull in Pounds: Minimum
		259	260	261	262	263	264	265	266	267
301	40-43-F	30286	0	1860		1860	28426	20605	21078	20030
302	40-45-F	32765	0	2365		2365	30400	22149	22605	21078
303	40-48-F	34107	0	1330		1330	32777	24105	24606	23525
305	80-45-F	51739	0	500		500	51239	19398	19930	18731
306	80-42-F	46733	0	485		485	46248	16879	17674	15753
308	80-53-F	57102	0	0		0	57102	21815	22854	21228
309	80-57-F	64636	0	0		0	64636	24539	25028	23160
311	120-51-F							15297	15603	15054
312	160-47-F	63930	0	10		10	63920	9138	9503	8804
313	160-50-F	69947	0	15		15	69932	10308	10665	10050
316	160-62-F	37571	0	20		20	37551	10762	14000	9401
317	160-50-P	37924	0	60		60	37864	9102	9655	8753
318	160-61-P	68306	0	115		115	68191	9530	9999	9145
319	160-65-P	69507	0	30		30	69477	9236	9605	8144

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards: Cut-off, Per Cent. of Stroke: High Pressure Cylinder: Right Side: Head End	Cut-off: High Pressure: Right Side: Crank End	Cut-off: High Pressure: Left Side: Head End	Cut-off: High Pressure: Left Side: Crank End	Cut-off: Low Pressure Cylinder: Right Side: Head End	Cut-off: Low Pressure: Right Side: Crank End	Cut-off: Low Pressure: Left Side: Head End	Cut-off: Low Pressure: Left Side: Crank End	Release, Per Cent. of Stroke: High Pressure Cylinder: Right Side: Head End	Release: High Pressure: Right Side: Crank End	Release: High Pressure: Left Side: Head End	Release: High Pressure: Left Side: Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
301	40-43-F			45.5	40.7	53.5	49.5					77.6	74.7
302	40-45-F			48.9	41.6	56.2	51.8					79.7	77.6
303	40-48-F			51.5	45.6	58.8	53.9					82.0	79.6
305	80-45-F			49.0	42.4	53.9	48.8					80.0	79.5
306	80-42-F			44.0	40.3	50.6	45.4					79.0	78.4
308	80-53-F			54.4	51.2	62.4	60.0					82.7	82.5
309	80-57-F			59.2	55.8	66.6	64.2					86.3	84.5
311	120-51-F			52.3	48.9	56.4	51.2					83.1	77.1
312	160-47-F			51.6	47.5	54.9	50.5					80.5	74.2
313	160-50-F			52.4	49.0	57.6	53.2					80.0	77.2
316	160-62-F			64.7	63.8	65.9	62.6					83.6	83.1
317	160-50-P			52.1	50.9	57.0	52.7					80.9	78.7
318	160-61-P			61.2	59.4	65.5	61.6					82.1	80.7
319	160-65-P			66.7	65.3	71.8	69.3					83.9	84.7

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585, MICHIGAN CENTRAL RAILROAD COMPANY.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
301	40-43-F	77.8	74.4					21.8	19.5	24.8	22.2		
302	40-45-F	78.6	75.7					20.9	17.8	23.0	20.6		
303	40-48-F	80.3	76.9					18.9	16.4	21.4	18.3		
305	80-45-F	80.6	77.4					19.8	18.9	21.6	19.2		
306	80-42-F	76.5	73.5					21.8	20.4	24.6	21.5		
308	80-53-F	82.8	80.8					17.7	16.1	18.3	15.8		
309	80-57-F	84.8	84.0					14.8	13.2	14.6	13.1		
311	120-51-F	79.3	75.4					23.4	20.5	24.1	18.4		
312	160-47-F	78.9	74.8					25.2	21.7	27.4	22.6		
313	160-50-F	80.6	76.7					24.4	18.1	28.1	22.8		
316	160-62-F	85.2	81.9					18.3	16.2	22.3	18.7		
317	160-50-P	82.4	78.3					24.5	20.3	29.1	24.4		
318	160-61-P	83.2	81.6					22.6	18.0	26.7	21.7		
319	160-65-P	86.9	83.9					16.4	16.9	27.5	20.9		

Test Number	Laboratory Designation	Pressure from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
301	40-43-F			208.6	205.3	77.1	75.7			1.1948
302	40-45-F			208.3	203.6	75.8	73.9			1.1955
303	40-48-F			209.9	206.1	76.8	72.9			1.1928
305	80-45-F			203.4	201.8	74.5	72.4			1.1978
306	80-42-F			200.7	197.2	68.9	66.9			1.1940
308	80-53-F			200.9	196.4	71.5	69.5			1.1955
309	80-57-F			207.6	200.0	73.2	71.9			1.1972
311	120-51-F			210.1	203.7	72.6	70.3			
312	160-47-F			241.1	216.0	81.4	74.6			1.1909
313	160-50-F			231.2	214.9	78.0	73.8			1.1972
316	160-62-F			182.4	170.8	76.4	66.4			1.1974
317	160-50-P			208.8	184.3	74.9	63.3			1.1978
318	160-61-P			176.7	167.9	73.9	68.2			1.1959
319	160-65-P			144.2	137.4	61.9	62.2			1.1951

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

Michigan Central Railroad Company.

Test Number	Laboratory Designation	Pressures from Indicator Cards								
		Steam Chest Pressures, Pounds Per Square Inch					Pressures at Cut-off, Pounds Per Square Inch			
		High Pressure		Low Pressure			High Pressure Cylinder			
							Right Side		Left Side	
		Right Side	Left Side	Right Side	Left Side		Head End	Crank End	Head End	Crank End
		301	302	303	304	305	306	307	308	309
301	40–43–F		209.7	66.6					178.6	175.6
302	40–45–F		208.9	67.0					183.2	182.9
303	40–48–F		209.9	68.5					186.6	189.1
305	80–45–F		205.5	67.7					171.5	176.9
306	80–42–F		206.0	62.6					169.9	169.5
308	80–53–F		205.4	65.1					170.9	171.8
309	80–57–F		210.9	66.7					178.7	178.4
311	120–51–F		208.0	65.0					151.3	150.0
312	160–47–F		209.3	63.4					130.7	134.1
313	160–50–F		204.4	66.8					136.3	144.5
316	160–62–F		172.4	60.6					110.4	110.4
317	160–50–P		184.8	58.6					121.3	120.5
318	160–61–P		157.6	57.6					104.2	107.4
319	160–65–P		134.2	52.3					93.1	94.0

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Cut-off, Pounds Per Square Inch				Pressures at Release, Pounds Per Square Inch							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
301	40–43–F	50.5	48.9					109.5	98.9	30.1	30.2		
302	40–45–F	50.8	50.9					113.1	96.6	33.2	31.3		
303	40–48–F	52.3	52.8					119.2	112.0	35.1	32.9		
305	80–45–F	48.3	48.2					108.7	99.4	28.8	26.7		
306	80–42–F	42.9	43.4					100.0	89.9	25.3	23.1		
308	80–53–F	45.8	43.1					117.1	110.3	32.0	29.3		
309	80–57–F	50.4	48.5					125.2	120.5	37.3	34.8		
311	120–51–F	41.1	41.3					95.1	97.0	24.6	24.6		
312	160–47–F	35.3	32.9					84.5	90.7	20.7	18.9		
313	160–50–F	37.5	35.1					92.8	94.4	23.0	21.4		
316	160–62–F	34.4	31.7					84.6	85.0	23.5	24.2		
317	160–50–P	32.0	31.3					78.1	80.7	18.4	17.0		
318	160–61–P	29.4	28.3					79.2	80.1	20.3	18.6		
319	160–65–P	25.7	25.2					72.3	73.0	17.3	18.4		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

Michigan Central Railroad Company.

Test Number	Laboratory Designation	Pressures from Indicator Cards — Pressures at Beginning of Compression, Pounds Per Square Inch — High Pressure Cylinder — Right Side — Head End	Crank End	Left Side — Head End	Crank End	Low Pressure Cylinder — Right Side — Head End	Crank End	Left Side — Head End	Crank End	Least Back Pressure, Pounds Per Square Inch — High Pressure Cylinder — Right Side — Head End	Crank End	Left Side — Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
301	40-43-F			82.1	80.4	2.3	1.8					66.4	64.1
302	40-45-F			80.1	79.1	.8	1.0					66.1	62.0
303	40-48-F			80.3	79.0	1.4	1.9					65.5	63.1
305	80-45-F			83.4	79.6	7.2	6.3					63.5	60.4
306	80-42-F			78.5	75.5	6.7	6.4					64.4	57.5
308	80-53-F			80.6	76.3	6.7	5.9					63.6	59.7
309	80-57-F			82.5	77.4	7.3	7.1					66.1	62.3
311	120-51-F			90.8	84.3	13.0	14.0					61.0	60.6
312	160-47-F			97.6	96.4	17.6	17.9					63.3	63.5
313	160-50-F			98.0	100.1	22.0	18.4					66.1	65.6
316	160-62-F			83.2	82.7	23.5	24.2					55.9	54.4
317	160-50-P			86.6	87.4	15.6	12.2					60.0	57.9
318	160-61-P			79.0	76.8	16.1	16.0					52.6	52.2
319	160-65-P			69.3	64.6	11.9	15.6					46.9	46.7

Test Number	Laboratory Designation	Pressures from Indicator Cards — Least Back Pressure, Pounds Per Square Inch — Low Pressure Cylinder — Right Side — Head End	Crank End	Left Side — Head End	Crank End	Boiler — Dry Coal Fired Pounds — Per Hour	Per Hour Per Square Foot of Grate Surface	Evaporation, Pounds — Steam Per Hour — Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
301	40-43-F	.1	.9			1027	20.78	9475	9358	3.319	9.111
302	40-45-F	.0	.7			1018	20.49	10133	10009	3.550	9.882
303	40-48-F	.7	1.1			1073	21.70	10926	10801	3.832	10.069
305	80-45-F	3.3	3.6			1770	35.81	17079	16867	5.984	9.528
306	80-42-F	3.0	2.8			1683	34.05	15416	15223	5.400	9.045
308	80-53-F	4.0	4.2			2087	42.22	19034	18800	6.669	9.009
309	80-57-F	5.7	5.9			2559	51.77	21545	21300	7.556	8.324
311	120-51-F	5.9	6.4								
312	160-47-F	6.1	6.1			2687	54.37	21306	21054	7.468	7.757
313	160-50-F	7.6	7.5			2767	55.97	23311	23032	8.170	8.325
316	160-62-F	8.6	8.8			3876	78.41	25030	24801	8.798	6.399
317	160-50-P	5.4	4.6			2444	49.44	20724	20486	7.267	8.383
318	160-61-P	6.5	6.8			2738	55.40	22730	22463	7.968	8.203
319	160-65-P	6.5	7.0			2638	53.36	23159	22900	8.123	8.682

For steam lost from boiler and not delivered to engines, see item 216.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

Michigan Central Railroad Company.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Boiler: Equiv't Evap'n: Per Hour, Per Sq. Ft. of Heat. Surface	Boiler: Equiv't Evap'n: Per Pound of Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Dry Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Engines: High Pressure Cylinder: Right Side: Crank End	Engines: High Pressure Cylinder: Left Side: Head End	Engines: High Pressure Cylinder: Left Side: Crank End
		344	345	346	347	348	349	350	351	352	353	354
301	40–43–F	11180	3.97	10.73	10.89	11.60	324.1	70.34			68.40	63.66
302	40–45–F	11966	4.25	11.64	11.82	12.50	346.7	76.88			76.55	71.58
303	40–48–F	12884	4.57	11.88	12.01	12.91	373.5	78.42			81.17	81.07
305	80–45–F	20205	7.17	11.32	11.41	12.33	585.6	74.16			70.20	67.88
306	80–42–F	18178	6.45	10.71	10.80	11.59	526.9	70.29			64.17	60.18
308	80–53–F	22476	7.97	10.66	10.77	11.89	651.5	68.96			79.25	78.62
309	80–57–F	25501	9.05	9.87	9.97	10.56	739.2	64.18			90.40	89.78
311	120–51–F										55.91	59.95
312	160–47–F	25075	8.89	9.23	9.24	9.92	726.8	60.41			33.59	39.69
313	160–50–F	27576	9.78	9.89	9.97	10.62	799.3	64.82			38.98	44.60
316	160–62–F	29700	10.53	7.61	7.66	8.08	860.9	49.81			43.52	45.74
317	160–50–P	24538	8.70	9.94	10.04	10.64	711.2	64.62			35.48	39.74
318	160–61–P	26864	9.58	9.71	9.81	10.43	778.7	63.21			40.08	45.04
319	160–65–P	27370	9.71	10.26	10.38	11.08	793.8	67.33			39.91	46.11

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square inch: Low Pressure Cylinder: Right Side: Head End	Low Pressure Cylinder: Right Side: Crank End	Low Pressure Cylinder: Left Side: Head End	Low Pressure Cylinder: Left Side: Crank End	Receiver Pressure	Receiver Pressure	Number of Expansions: Head End	Number of Expansions: Crank End	Number of Expansions: Head End	Number of Expansions: Crank End
		355	356	357	358	359	360	361	362	363	364
301	40–43–F	43.95	41.56			74.0		3.03	3.30		
302	40–45–F	45.95	43.92			71.9		2.95	3.30		
303	40–48–F	48.84	46.03			71.1		2.90	3.14		
305	80–45–F	38.98	37.07			—		3.02	3.33		
306	80–42–F	33.12	31.33			—		3.11	3.29		
308	80–53–F	41.75	40.30			70.0		2.86	3.01		
309	80–57–F	46.16	43.80			73.4		2.74	2.92		
311	120–51–F	30.26	28.88								
312	160–47–F	20.44	19.66			71.6		2.85	2.97		
313	160–50–F	22.32	21.52			72.9		2.87	2.97		
316	160–62–F	20.89	21.30			63.9		2.57	2.57		
317	160–50–P	19.43	21.50			66.1		2.94	2.94		
318	160–61–P	19.26	19.60			63.4		2.68	2.71		
319	160–65–P	19.79	18.38			56.2		2.56	2.58		

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No, 585.

Michigan Central Railroad Company.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure, Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
301	40–43–F			92.7	83.6	137.7	128.5				176.8	266.2	
302	40–45–F			103.7	94.0	148.9	135.8				197.7	279.7	
303	40–48 F			110.0	106.5	158.1	142.4				216.5	295.5	
305	80–45–F			189.9	178.1	243.9	228.8				367.9	472.7	
306	80–42–F			174.2	158.5	208.0	194.2				332.7	402.2	
308	80–53–F			214.7	206.6	261.6	249.2				421.3	510.9	
309	80–57–F			244.9	235.8	289.2	270.8				480.7	560.0	
311	120–51–F			223.3	232.2	279.5	263.2				455.5	542.7	
312	160–47–F			182.1	208.6	256.2	243.2				390.7	499.5	
313	160–50–F			211.2	234.4	279.8	266.2				445.6	546.0	
316	160–62–F			235.8	240.4	261.8	263.4				476.1	525.2	
317	160–50–P			192.2	208.8	243.5	265.9				401.0	509.3	
318	160–61–P			217.0	236.8	241.5	242.5				453.7	484.0	
319	160–65–P			216.8	242.4	248.1	227.4				458.7	475.5	

Test Number	Laboratory Designation	Engines						Locomotive			
		Division of Power			Consumed Per I. H. P., Hour			Dynamometer Horse Power	Pounds Per D. H. P., Hour		B. T. U. Per D. H. P. Hour
		Total		Total I. H. P.							
		Right Side	Left Side		Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.		Of Dry Coal	Of Dry Steam	
		377	378	379	380	381	382	383	384	385	386
301	40–43–F	266.2	176.8	442.5	2.22	20.20	33123	411.5	2.38	21.72	35619
302	40–45–F	279.7	197.7	477.4	2.03	20.09	30161	442.2	2.19	21.69	32561
303	40–48–F	295.5	216.5	512.0	2.01	20.27	29771	481.6	2.14	21.55	31652
305	80–45–F	472.7	367.9	840.6	2.05	19.54	30462	773.3	2.23	21.24	33120
306	80–42–F	402.2	332.7	734.9	2.23	20.15	33055	675.7	2.42	21.92	35955
308	80–53–F	510.9	421.3	932.2	2.19	19.69	32954	871.4	2.34	21.06	35251
309	80–57–F	560.0	480.7	1040.7	2.41	20.03	36585	980.0	2.56	21.27	38335
311	120–51–F	542.7	455.5	998.2				900.8			
312	160–47–F	499.5	390.7	890.1	2.96	23.18	43773	730.1	3.61	28.27	53360
313	160–50–F	546.0	445.6	991.6	2.74	22.80	40982	823.6	3.30	27.45	49342
316	160–62–F	525.2	476.1	1001.3	3.82	24.43	56690	859.7	4.44	28.45	66021
317	160–50–P	509.3	401.0	910.4	2.62	21.98	39336	727.0	3.28	27.52	49260
318	160–61–P	484.0	453.7	937.7	2.87	23.56	43632	761.4	3.54	29.01	52990
319	160–65–P	475.5	458.7	934.2	2.79	24.14	41391	737.9	3.52	30.56	52402

For Maximum Indicated Horse Power, see item 403.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

Michigan Central Railroad Company.

Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	I. H. P. Per Square Foot of: Heating Surface	Grate Surface	D. H. P. Per Square Foot of: Heating Surface	Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
301	40-43-F	1.20	10.97	17986	.1570	8.95	.1460	8.33	22154	30.98		1551
302	40-45-F	1.11	10.95	16441	.1693	9.66	.1568	8.94	23910	35.22		1764
303	40-48-F	1.08	10.88	15979	.1816	10.36	.1708	9.74	25622	30.43		1523
305	80-45-F	1.13	10.73	16724	.2182	17.01	.2743	15.64	21079	67.83		1686
306	80-42-F	1.22	11.08	18170	.2606	14.89	.2397	13.69	18335	59.21		1478
308	80-53-F	1.18	10.64	17812	.3306	18.86	.3091	17.63	23332	60.80		1522
309	80-57-F	1.29	10.49	19359	.3992	21.05	.3476	19.83	26058	60.71		1520
311	120-51-F				.3540	20.19	.3195	18.22	16953	97.38		1653
312	160-47-F	1.82	14.27	26953	.3157	18.01	.2590	14.77	11139	160.02		2003
313	160-50-F	1.67	13.87	24921	.3517	20.66	.2921	16.66	12410	168.02		2103
316	160-62-F	2.24	14.37	33341	.3552	20.26	.3049	17.39	12533	141.65		1773
317	160-50-P	1.66	13.90	24881	.3193	18.21	.2579	14.71	11395	183.85		2296
318	160-61-P	1.79	14.65	26761	.3326	18.97	.2701	15.40	11732	176.26		2206
319	160-65-P	1.78	15.43	26463	.3313	18.90	.2617	14.93	11688	196.82		2457

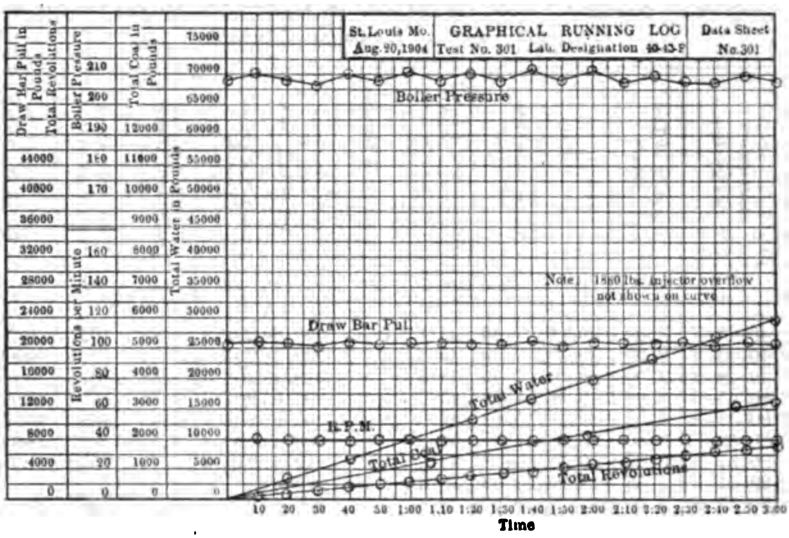
Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
301	40-43-F	93.00	7.15	413.4	6.17	815	457.2				8-20-04
302	40-45-F	92.63	7.82	394.4	5.88	876	479.7				8-20-04
303	40-48-F	94.06	8.04	360.4	5.38	954	524.5				8-25-04
305	80-45-F	91.99	7.68	217.4	3.24	1531	869.5				8-11-04
306	80-42-F	91.95	7.08	241.0	3.60	1337	784.2				8-13-04
308	80-53-F	93.48	7.22	196.6	2.93	1725	961.6				8-16-04
309	80-57-F	94.16	6.64	178.5	2.66	1941	1059.1				8-16-04
311	120-51-F	90.24				1784					8-22-04
312	160-47-F	82.02	4.77	201.9	3.01	1446	936.3				8-23-04
313	160-50-F	83.05	5.16	185.7	2.77	1631	1017.8				8-17-04
316	160-62-F	85.86	3.86	186.8	2.79	1702	1011.8				8-17-04
317	160-50-P	79.89	5.17	200.6	2.99	1439	942.2				8-24-04
318	160-61-P	81.20	4.80	190.7	2.84	1508	991.3				8-27-04
319	160-65-P	78.98	4.86	185.1	2.76	1461	1021.0				8-26-04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

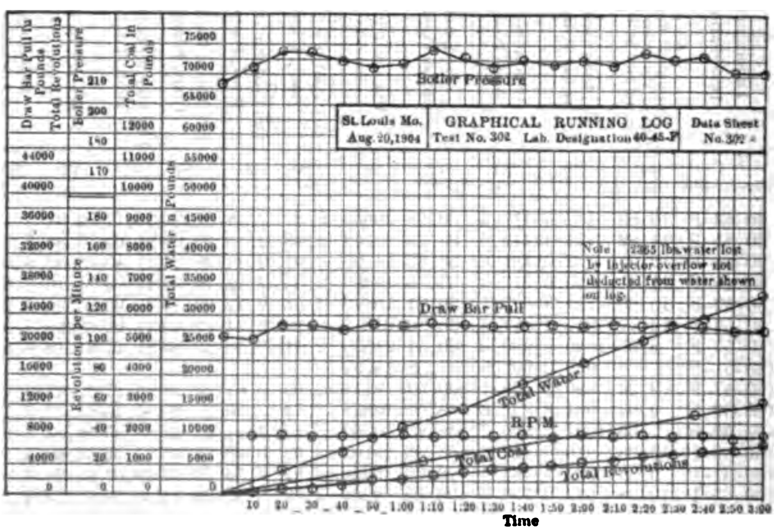
Michigan Central Railroad Company.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft, Front of Diaphragm, Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	203	217	220	222	338	341
301	40–43–F	3.00	40.00	7.49	43.1	Full	209.2	204.3	.68	1027	9358
302	40–45–F	3.00	39.99	7.49	45.3	"	209.1	204.0	.74	1013	10009
303	40–48–F	3.00	40.01	7.49	48.6	"	210.1	208.5	.88	1073	10801
305	80–45–F	3.00	79.86	14.96	45.7	"	209.6	204.7	1.95	1770	16867
306	80–42–F	3.00	80.18	15.01	42.2	"	205.8	202.0	1.43	1683	15223
308	80–53–F	3.00	80.00	14.98	52.8	"	206.4	203.9	2.37	2087	18800
309	80–57–F	3.00	79.98	14.98	57.5	"	210.9	210.9	3.19	2559	21300
311	120–51–F	.50	117.93	22.09	50.6	"	209.6		2.81		
312	160–47–F	3.00	160.02	29.97	49.6	"	209.0	202.7	2.74	2687	21054
313	160–50–F	3.00	160.01	29.97	50.7	"	209.3	207.7	3.65	2767	23032
316	160–62–F	1.50	159.97	29.96	64.3	"	175.1	169.4	5.02	3876	24801
317	160–50–P	1.83	159.95	29.96	51.5	19	208.7	177.0	2.78	2444	20486
318	160–61–P	3.00	160.03	29.97	60.3	17	210.7	160.5	3.38	2738	22463
319	160–65–P	3.00	160.01	29.97	66.0	19	208.3	136.5	3.56	2638	22900

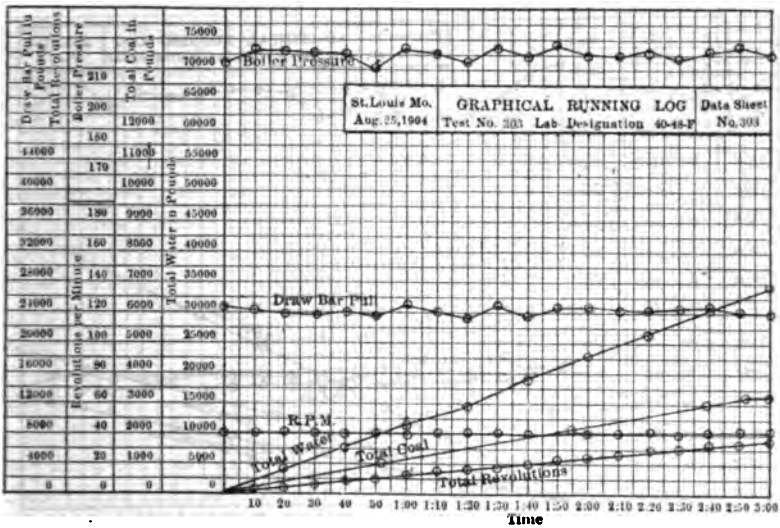
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		347	379	383	395	265	380	384	381	385	350	390
301	40–43–F	10.89	442.5	411.5	30.98	20605	2.22	2.38	20.20	21.72	70.34	7.15
302	40–45–F	11.82	477.4	442.2	35.22	22149	2.03	2.19	20.09	21.69	76.88	7.82
303	40–48–F	12.01	512.0	481.6	30.43	24105	2.01	2.14	20.27	21.55	78.42	8.04
305	80–45–F	11.41	840.6	773.3	67.33	19393	2.05	2.23	19.54	21.24	74.16	7.68
306	80–42–F	10.80	734.9	675.7	59.21	16879	2.23	2.42	20.15	21.92	70.29	7.08
308	80–53–F	10.77	932.2	871.4	60.80	21815	2.19	2.34	19.69	21.06	68.96	7.22
309	80–57–F	9.97	1040.7	980.0	60.71	24539	2.41	2.56	20.03	21.27	64.18	6.64
311	120–51–F		998.2	900.8	97.38	15297						
312	160–47–F	9.24	890.1	730.1	160.02	9138	2.96	3.61	23.18	28.27	60.41	4.77
313	160–50–F	9.97	991.6	823.6	168.02	10308	2.74	3.30	22.80	27.45	64.32	5.16
316	160–62–F	7.66	1001.3	859.7	141.65	10762	3.82	4.44	24.43	28.45	49.81	3.86
317	160–50–P	10.04	910.4	727.0	183.35	9102	2.62	3.28	21.98	27.52	64.62	5.17
318	160–61–P	9.81	937.7	761.4	176.26	9530	2.87	3.54	23.56	29.01	63.21	4.80
319	160–65–P	10.38	934.2	787.9	196.82	9236	2.79	3.52	24.14	30.56	67.33	4.86



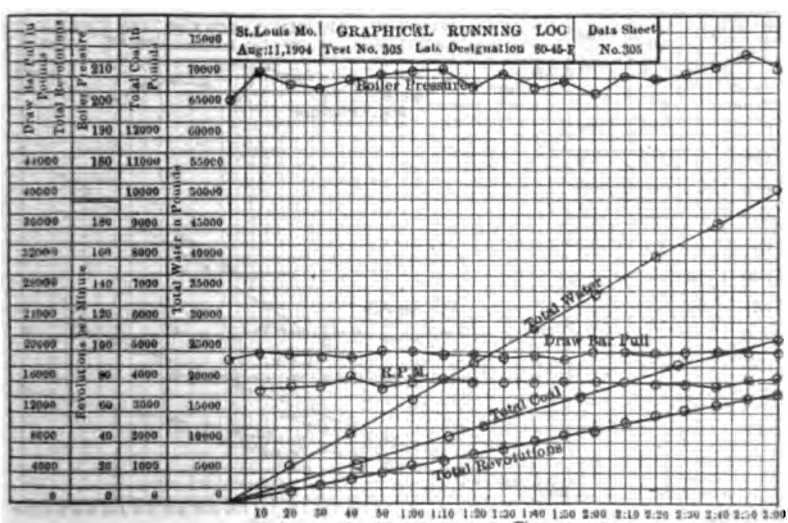
Test No. 301.



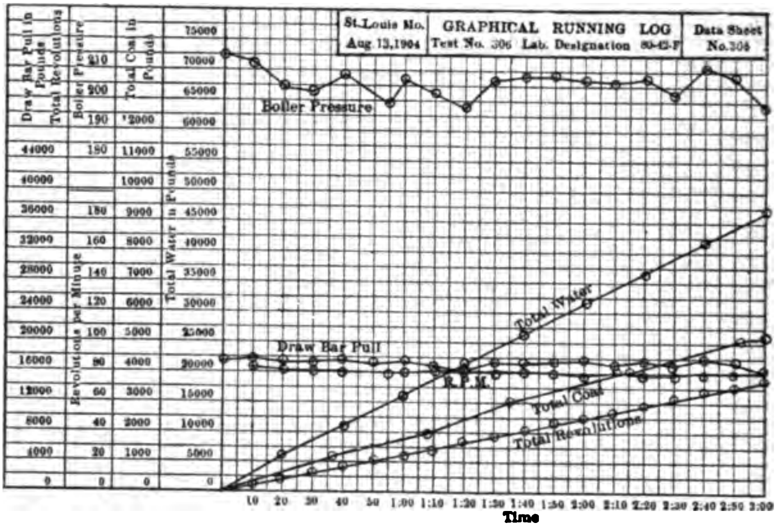
Test No. 302.



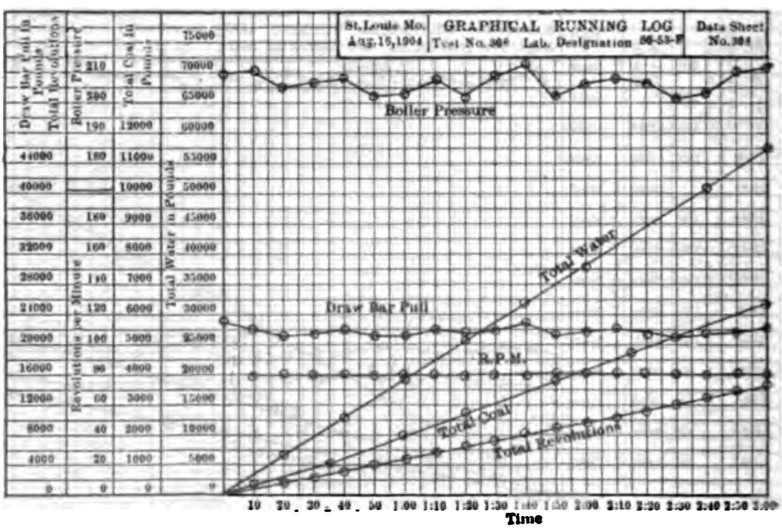
Test No. 303.



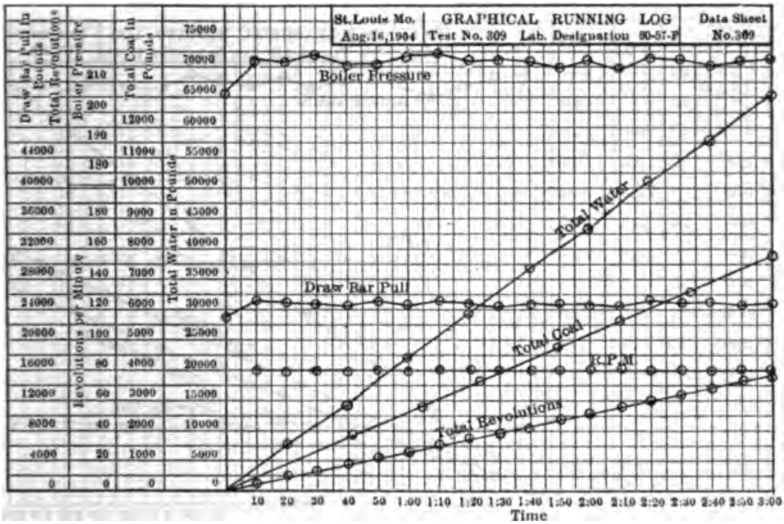
Test No. 305.



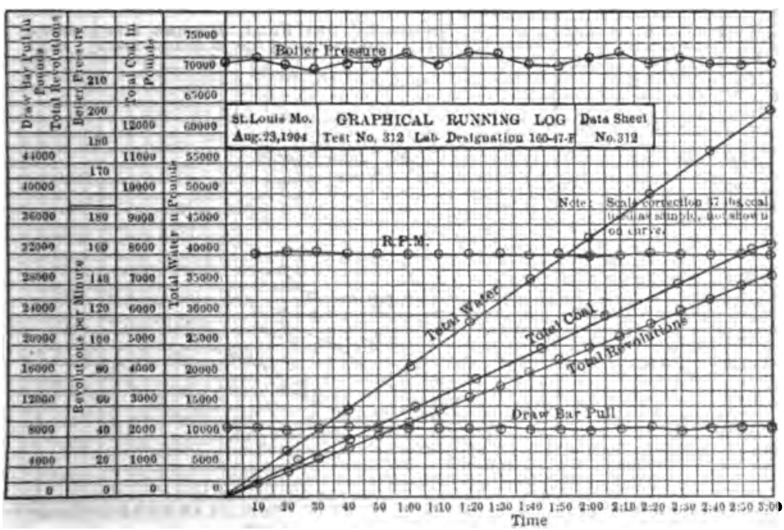
Test No. 306.



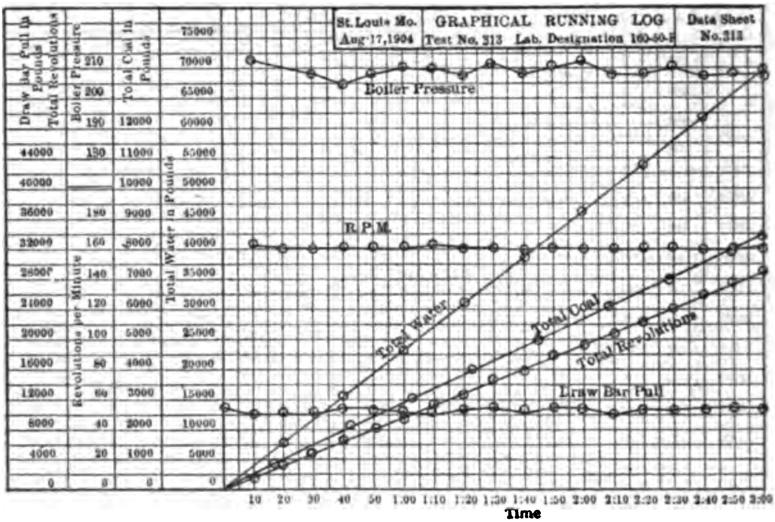
Test No. 308.



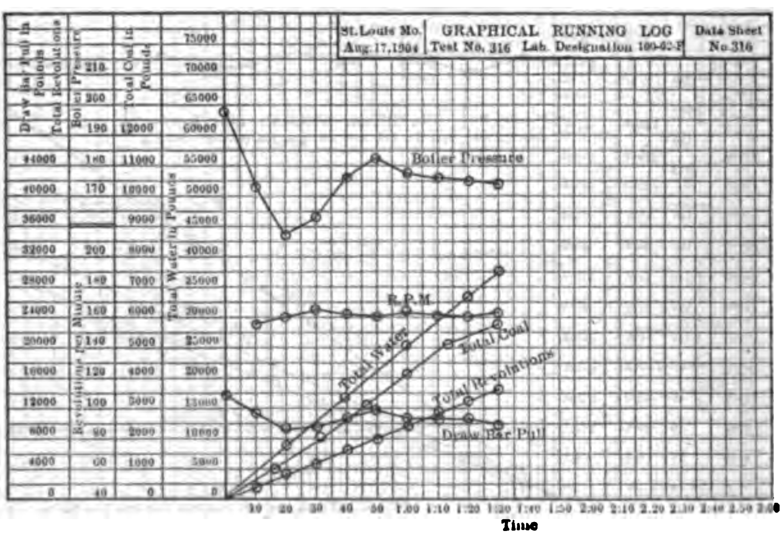
Test No. 309.



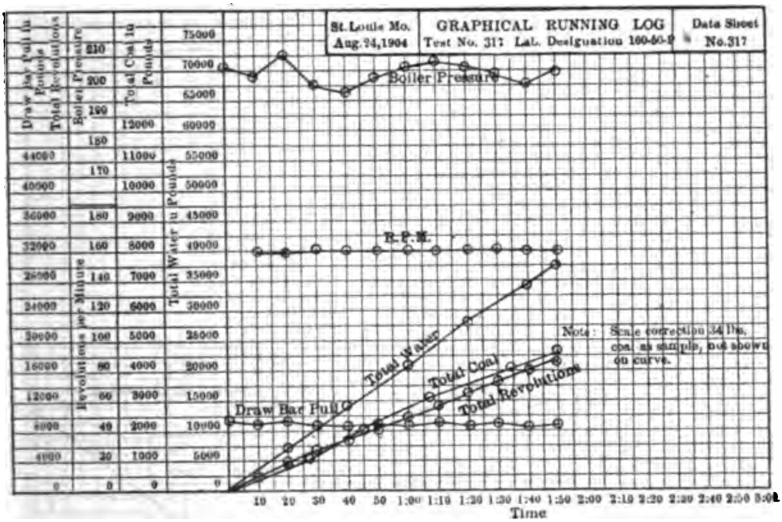
Test No. 312.



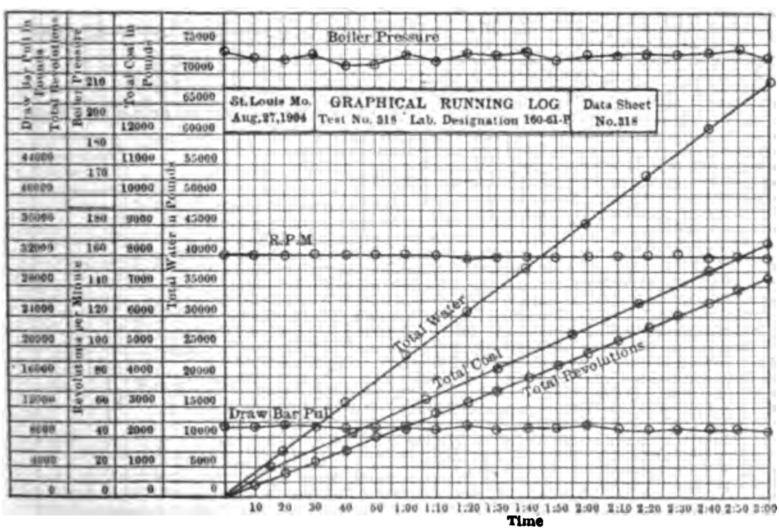
Test No. 313.



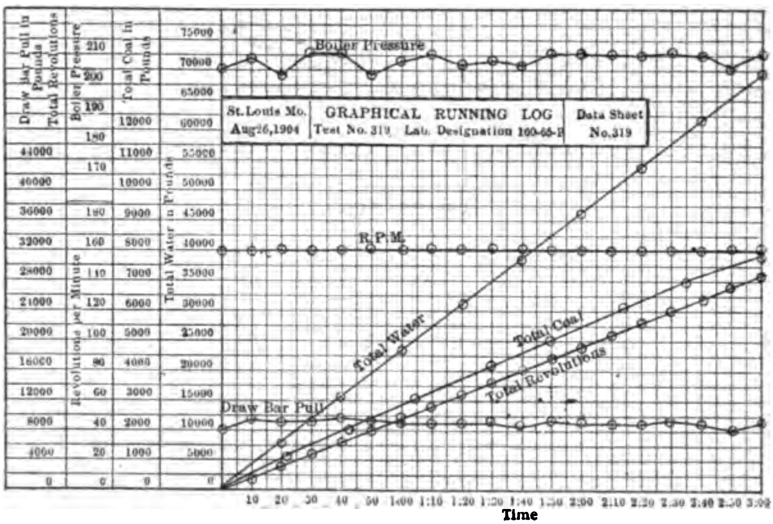
Test No. 316.



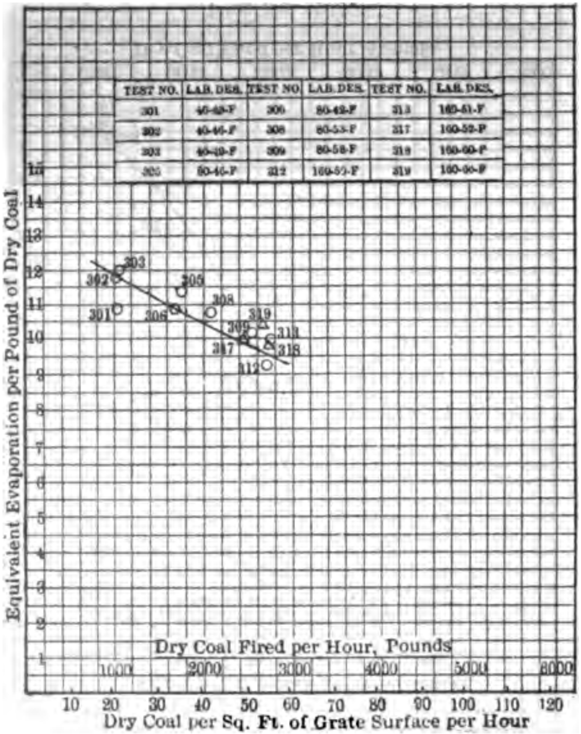
Test No. 317.



Test No. 318.

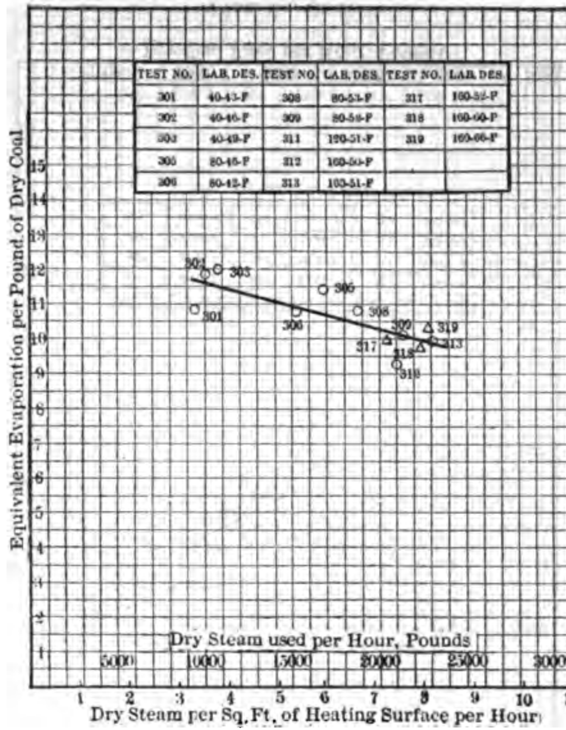

St. Louis Mo.
Aug 26, 1904
GRAPHICAL RUNNING LOG
Test No. 319 Lab. Designation 160-65-F
Data Sheet
No. 319
Draw Bar Pull in Pounds
Total Revolutions
Boiler Pressure
Total Coal in Pounds
Revolutions per Minute
Total Water in Pounds
Boiler Pressure
R.P.M.
Total Water
Total Coal
Total Revolutions
Draw Bar Pull
Time

Test No. 319.



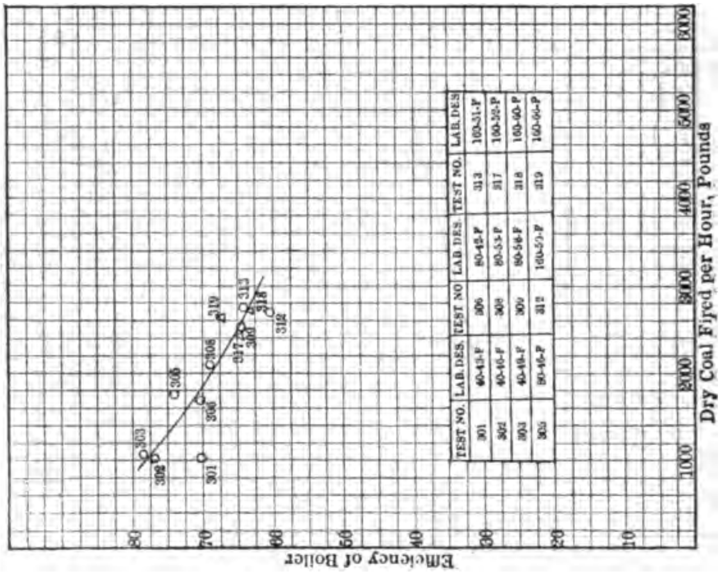
TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
301	40-43-F	306	80-42-F	313	100-51-F
302	40-46-F	308	80-53-F	317	100-52-F
303	40-49-F	309	80-58-F	318	100-60-F
305	80-46-F	312	100-50-F	319	100-66-F

Plot No. 301.

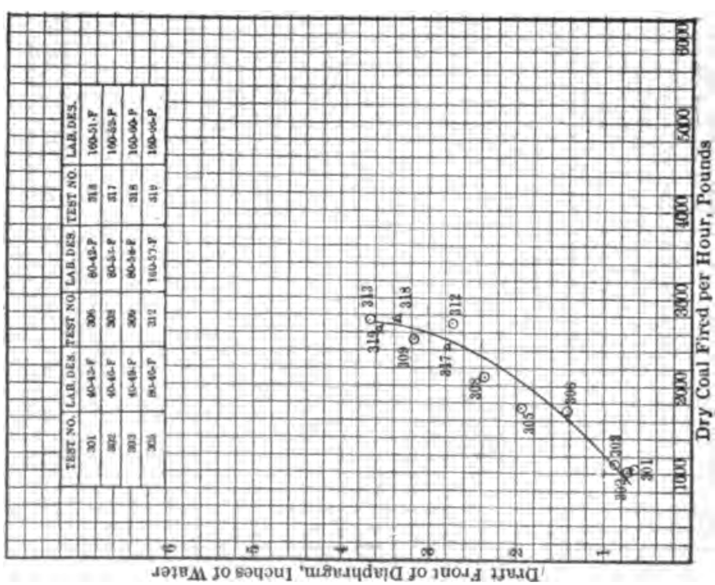


TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
301	40-43-F	308	80-53-F	317	100-52-F
302	40-46-F	309	80-58-F	318	100-60-F
303	40-49-F	311	100-51-F	319	100-66-F
305	80-46-F	312	100-50-F		
306	80-42-F	313	100-51-F		

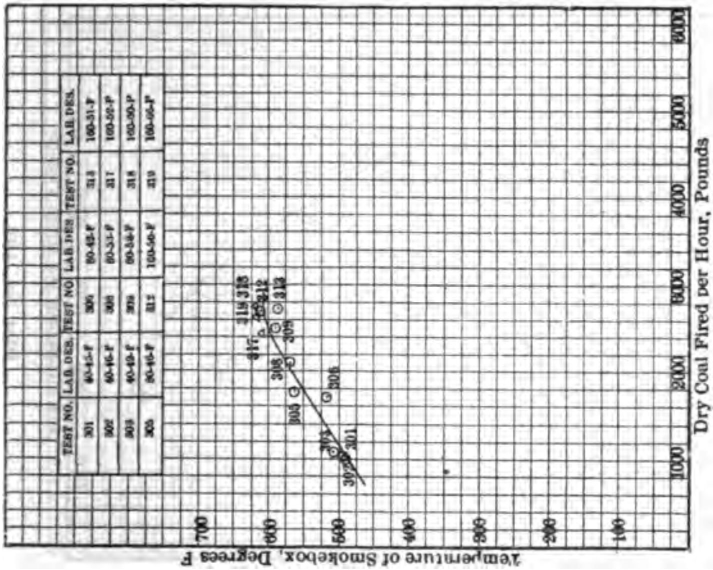
Plot No. 302.



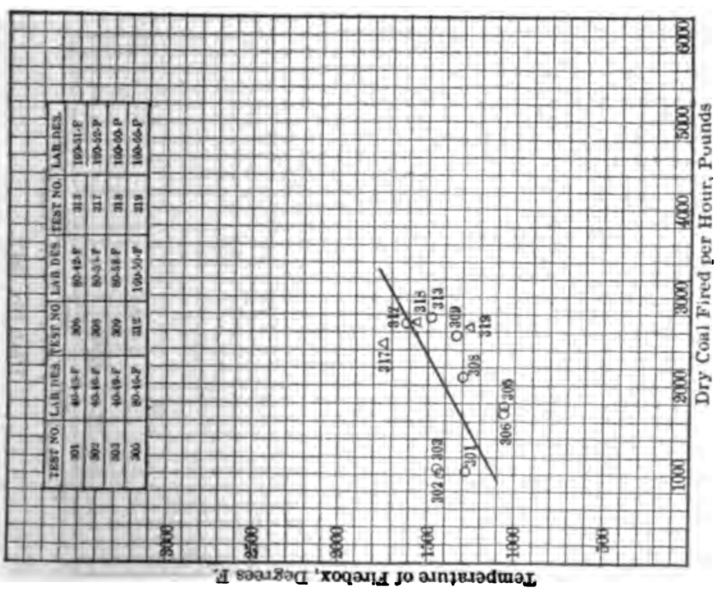
Plot No. 304.



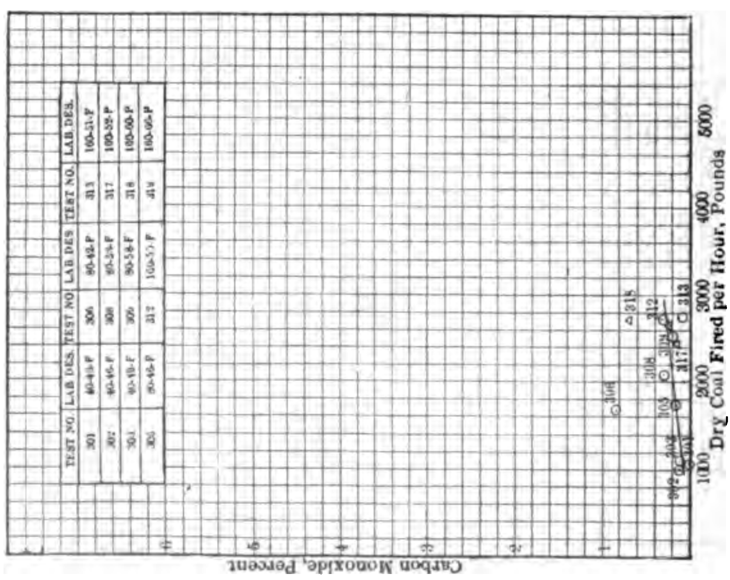
Plot No. 303.



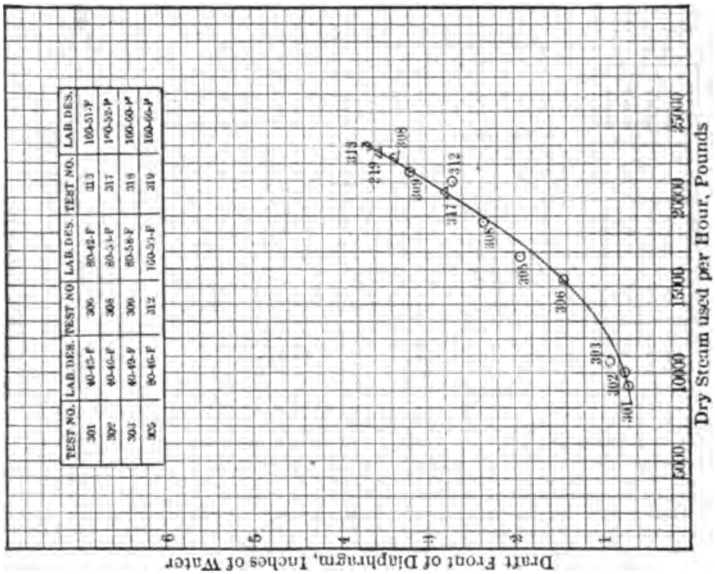
Plot No. 306.



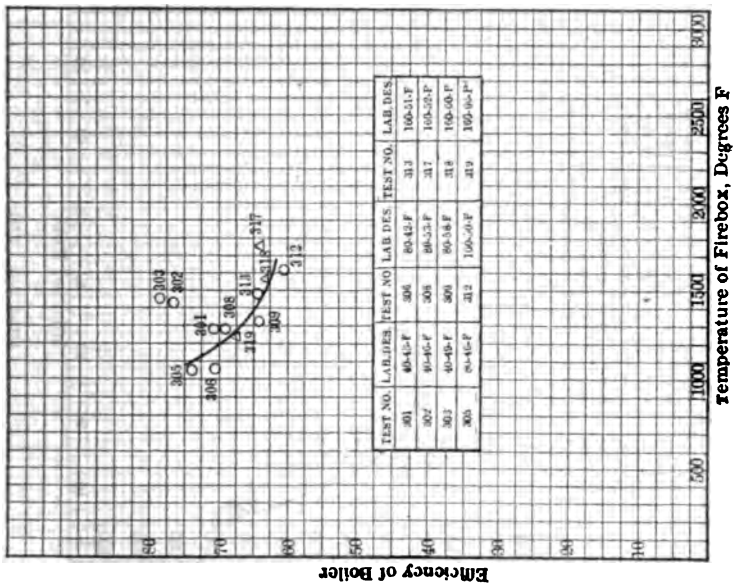
Plot No. 305.



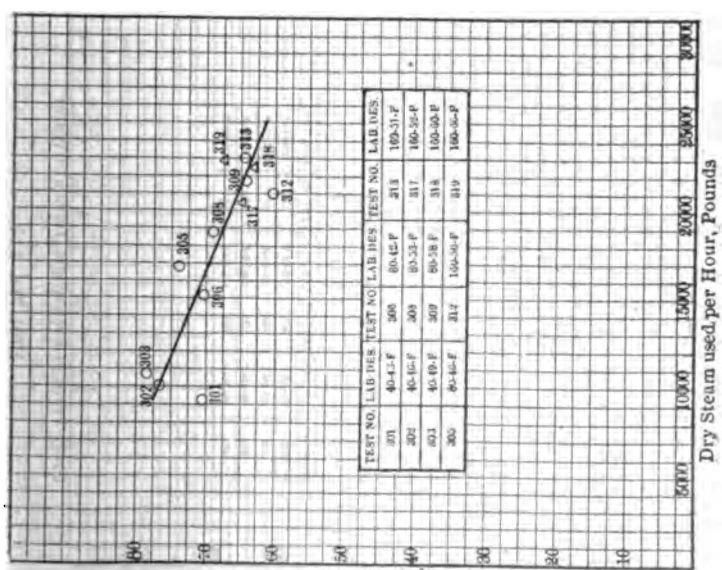
Plot No. 307.



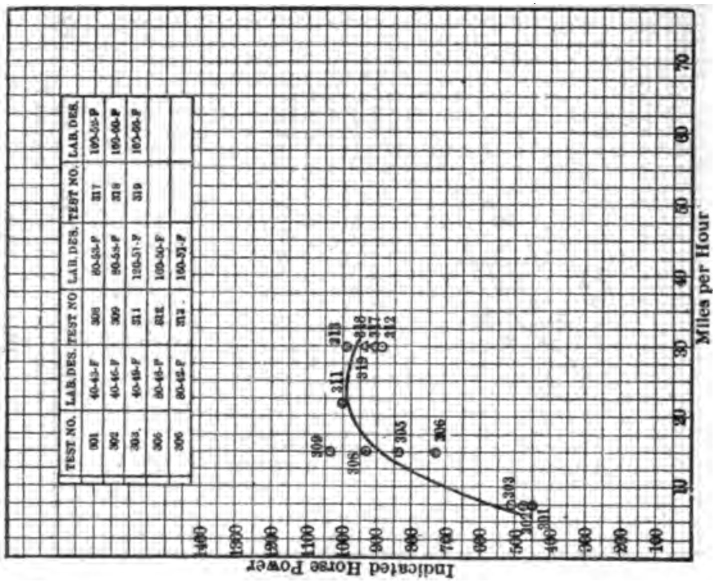
Plot No. 308.



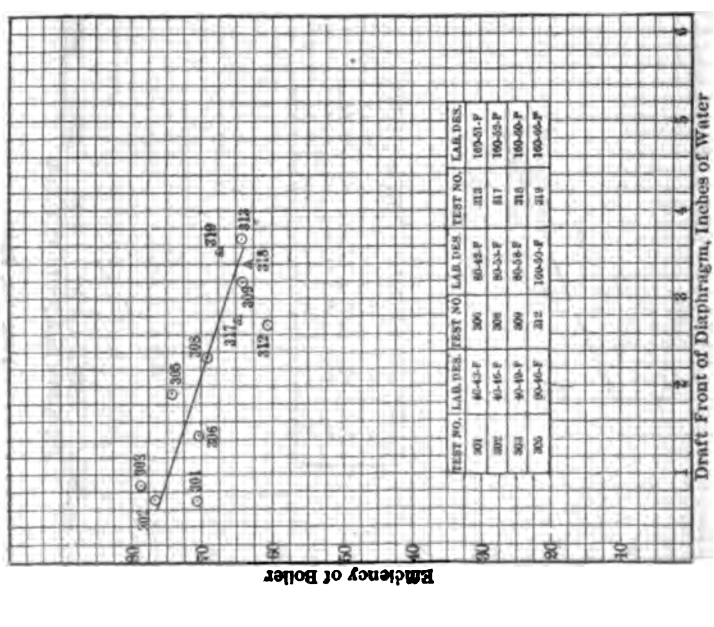
Plot No. 310.



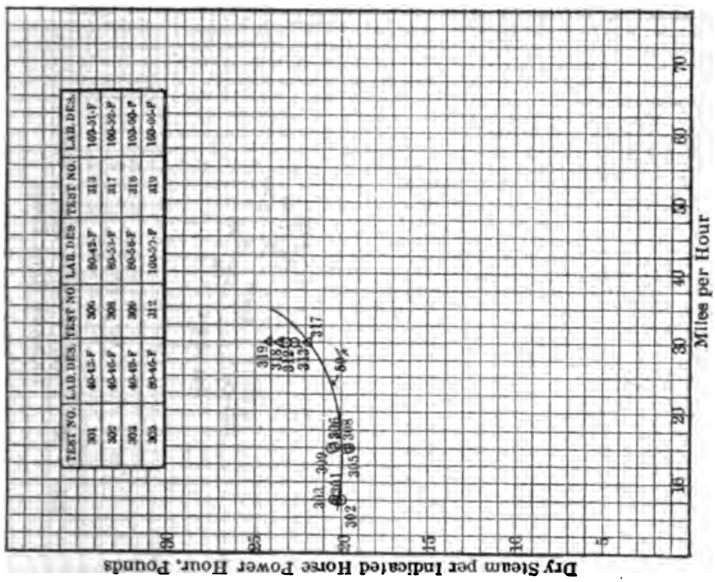
Plot No. 309.



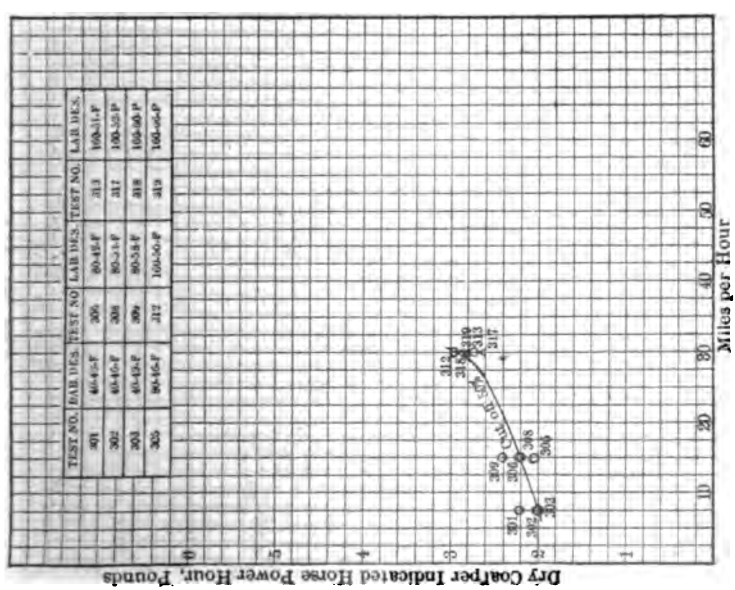
Plot No. 320.



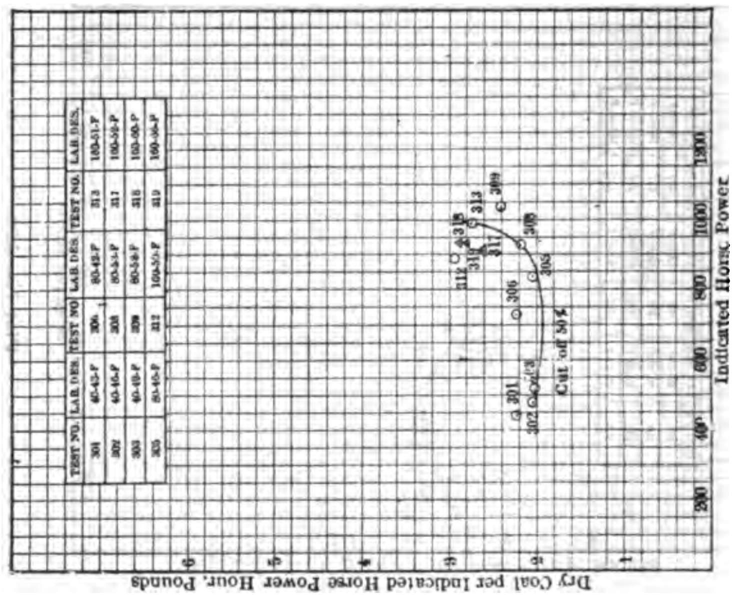
Plot No. 311



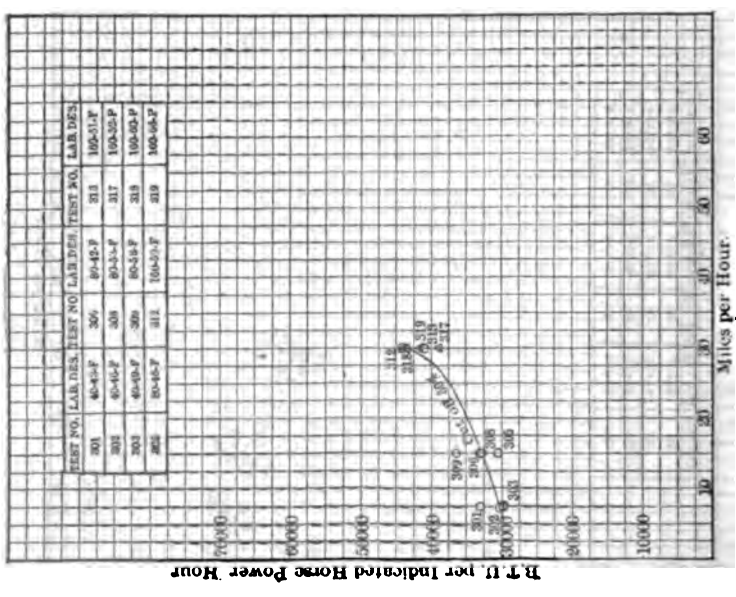
Plot No. 322.



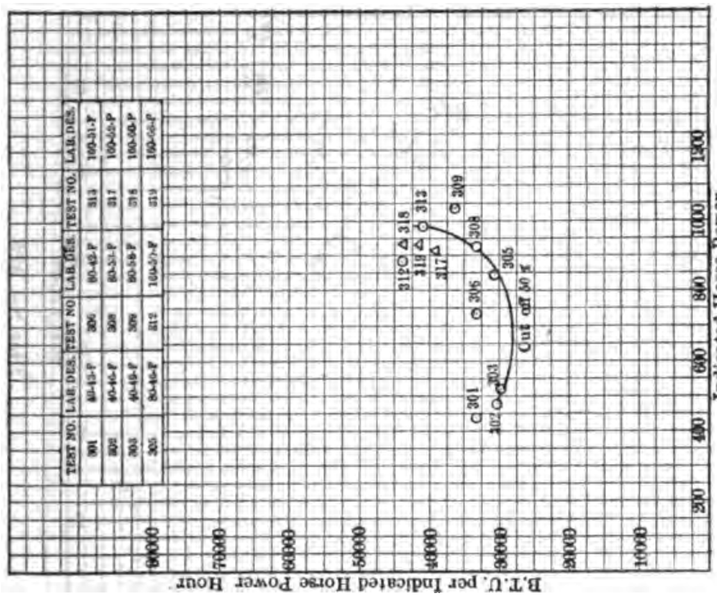
Plot No. 321.



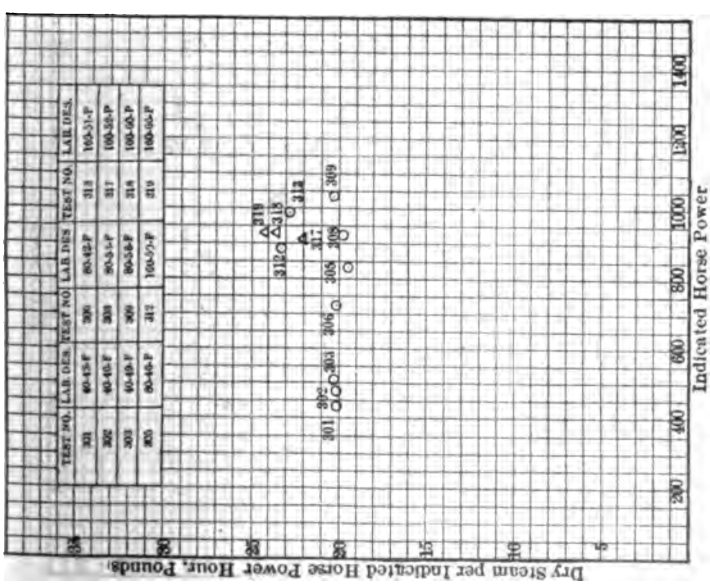
Plot No. 324.



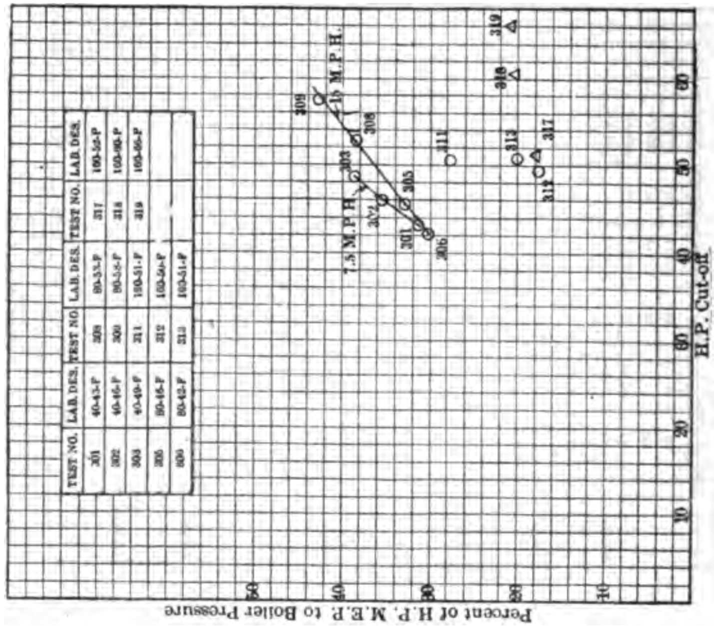
Plot No. 323.



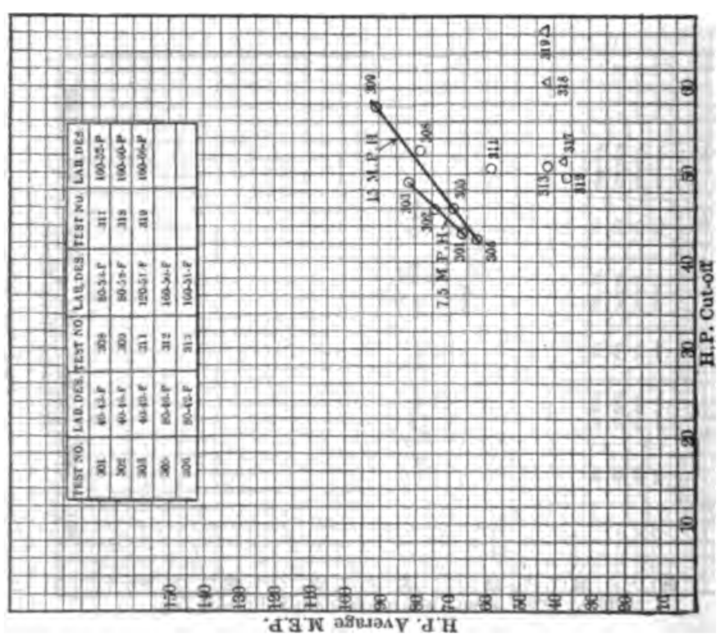
Plot No. 326.



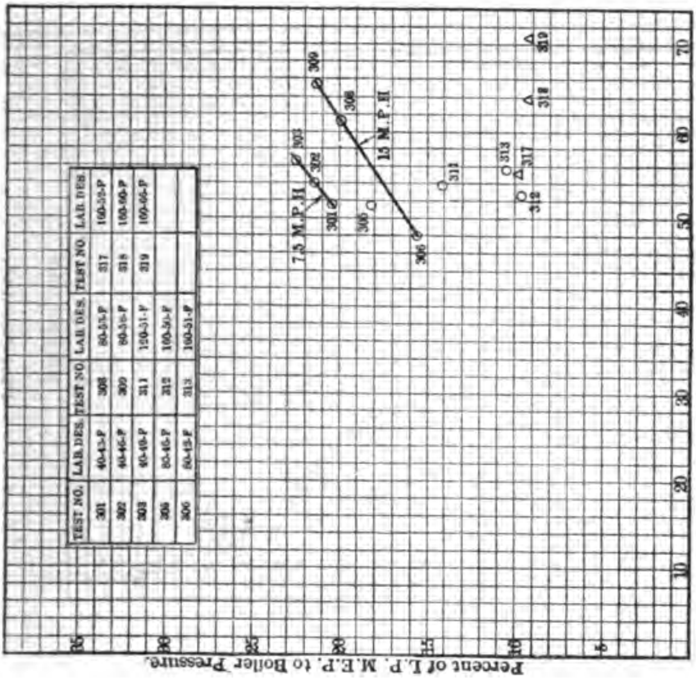
Plot No. 325.



Plot No. 328.

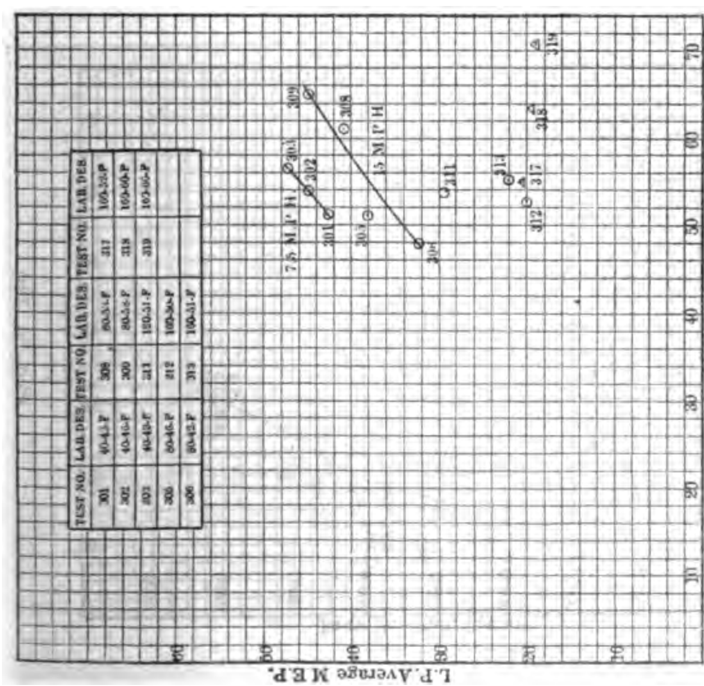


Plot No. 327.



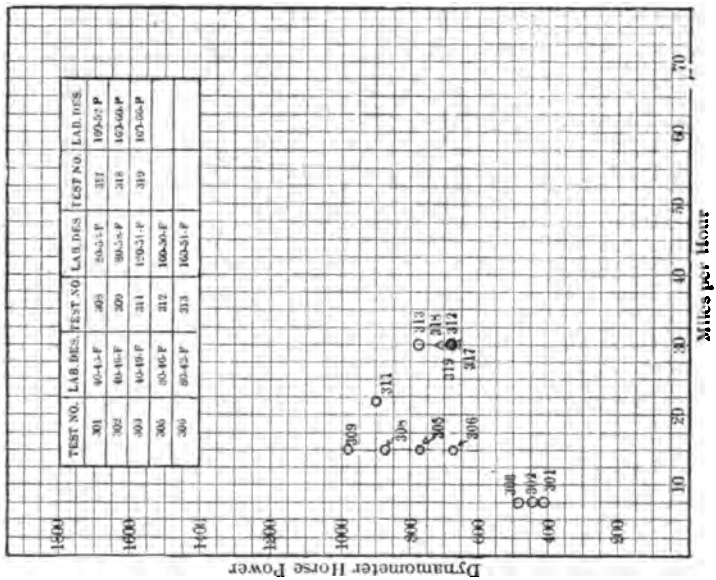
TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
301	40-43-P	308	80-55-P	317	160-59-P
302	40-46-P	309	80-56-P	318	160-60-P
303	40-49-P	311	120-51-P	319	160-66-P
305	80-46-P	312	160-50-P		
306	80-43-P	313	160-51-P		

Plot No. 330.

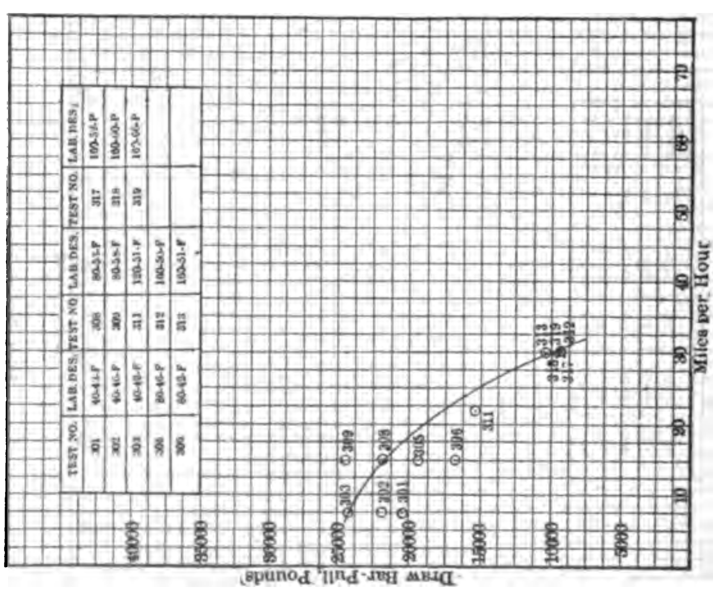


TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
301	40-43-P	308	80-55-P	317	160-59-P
302	40-46-P	309	80-56-P	318	160-60-P
303	40-49-P	311	120-51-P	319	160-66-P
305	80-46-P	312	160-50-P		
306	80-43-P	313	160-51-P		

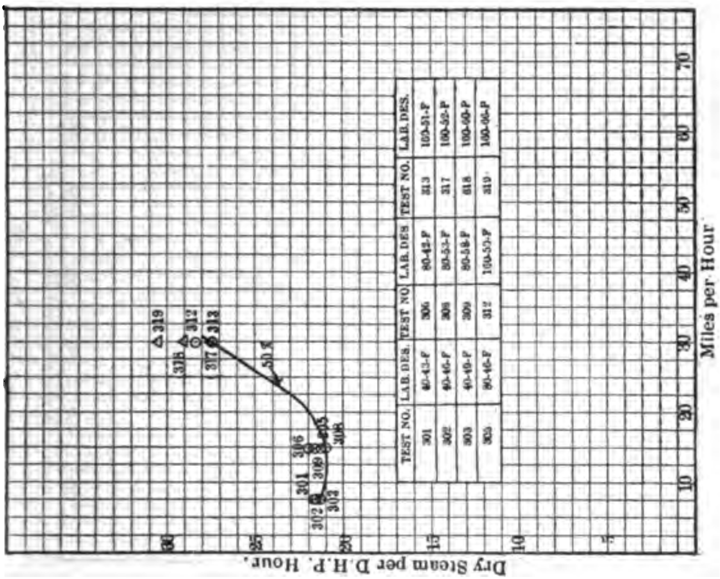
Plot No. 329.



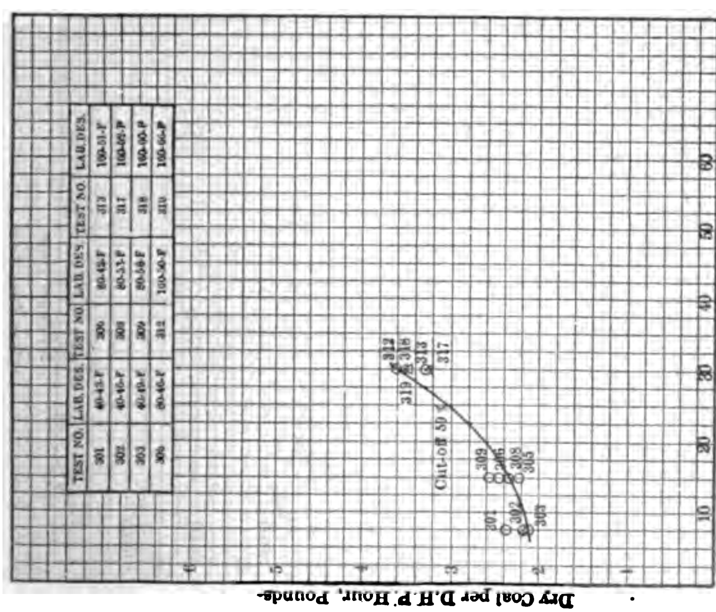
Plot No. 341.



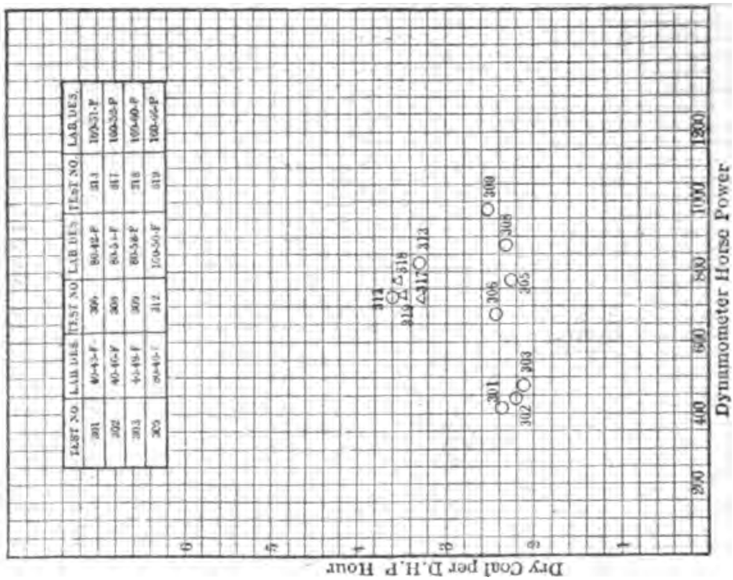
Plot No. 340.



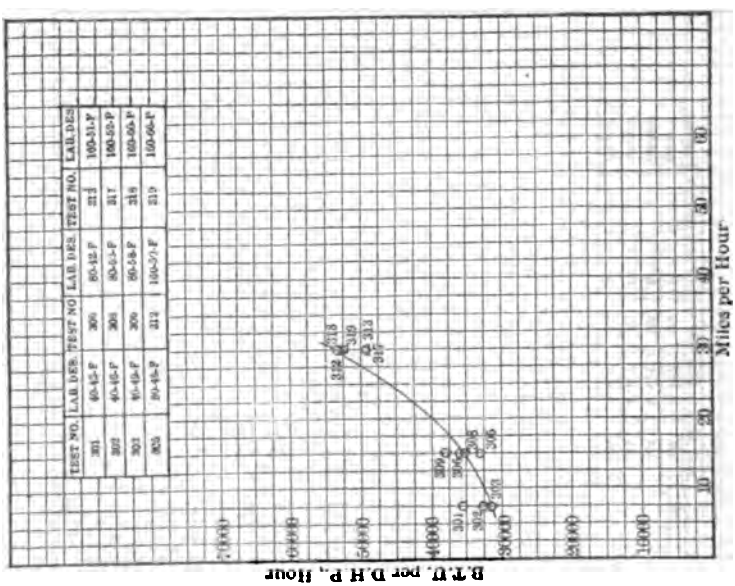
Plot No. 343.



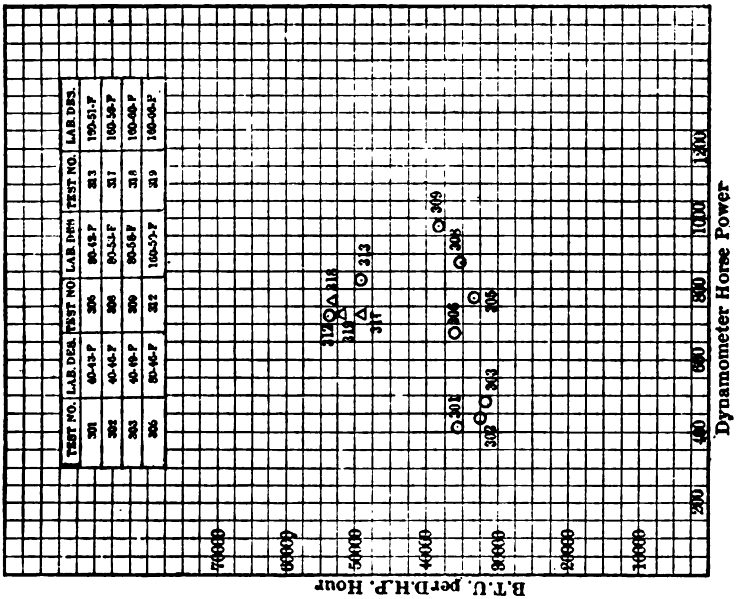
Plot No. 342.



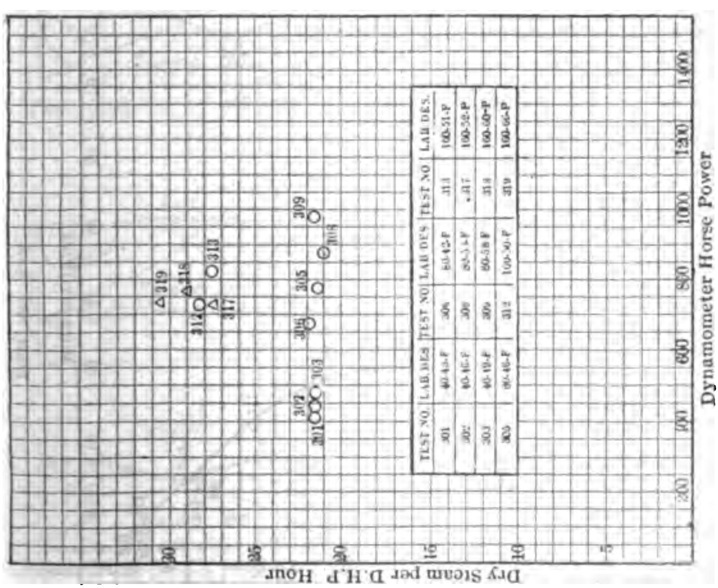
Plot No. 345.



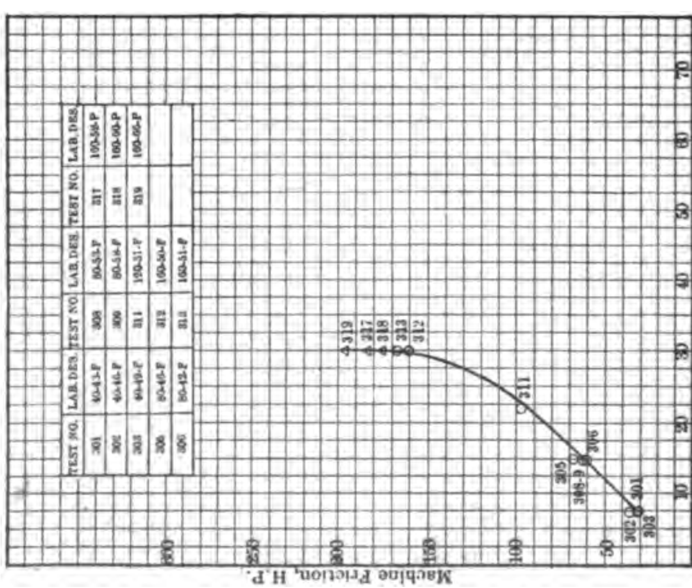
Plot No. 344.



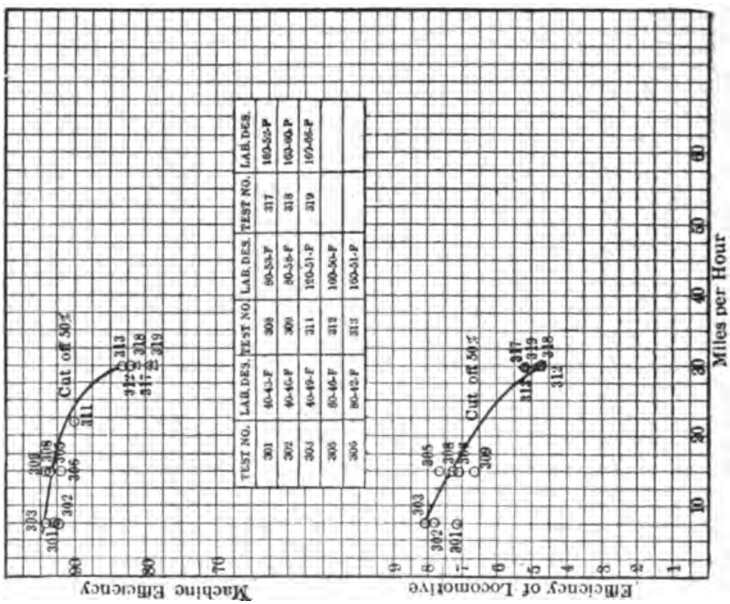
Plot No. 347.



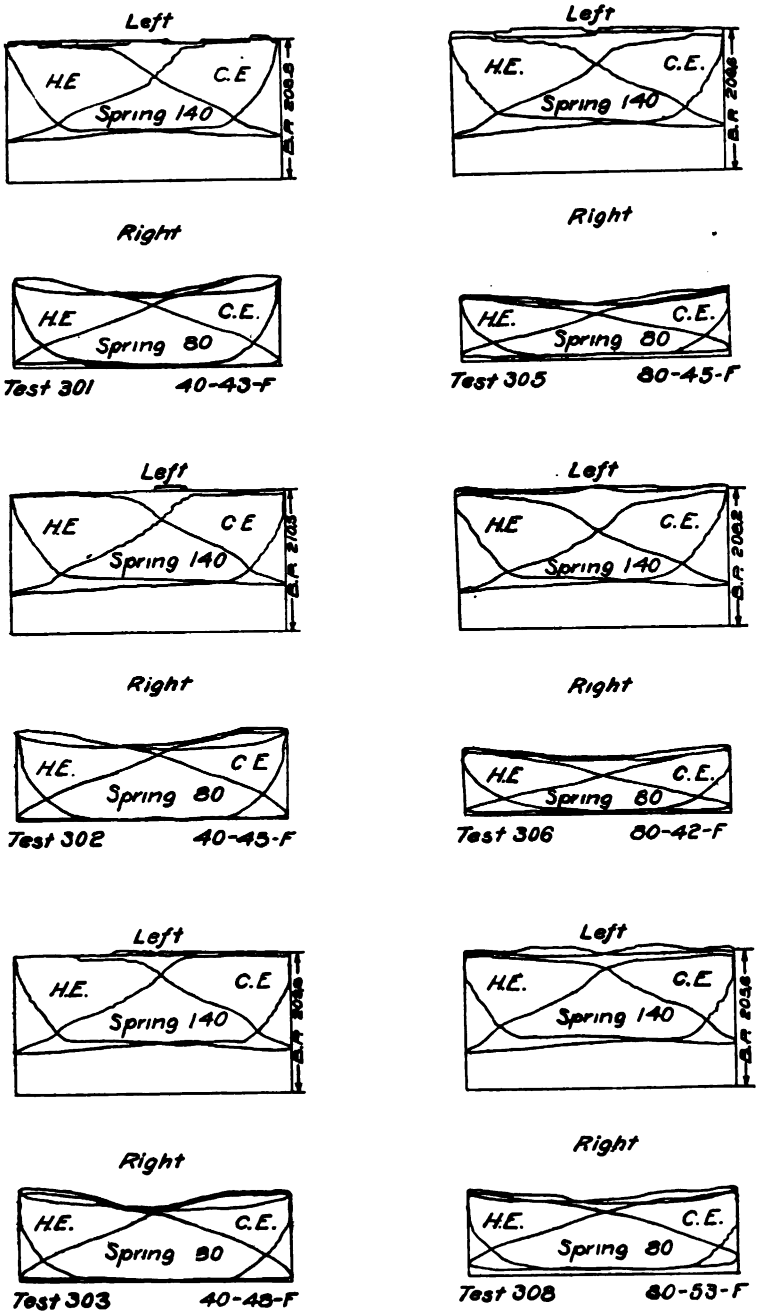
Plot No. 346.



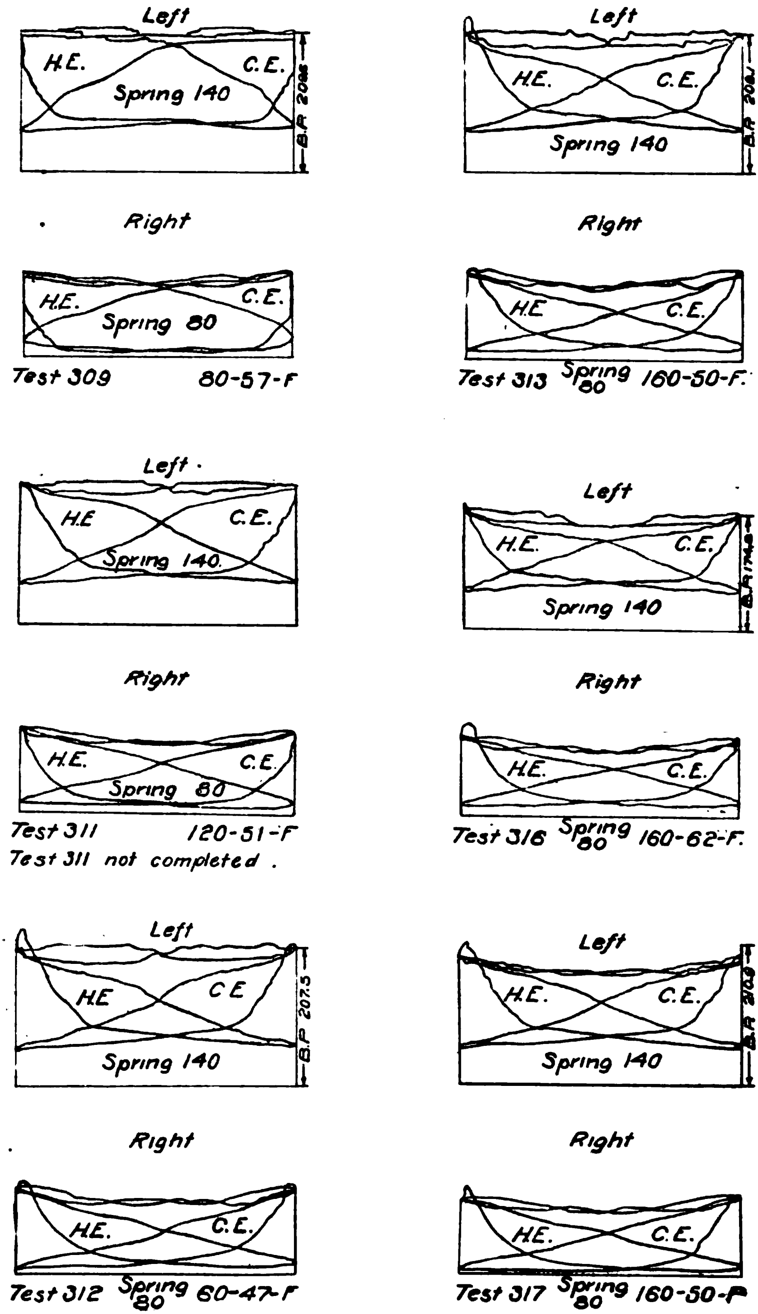
Plot No. 348.



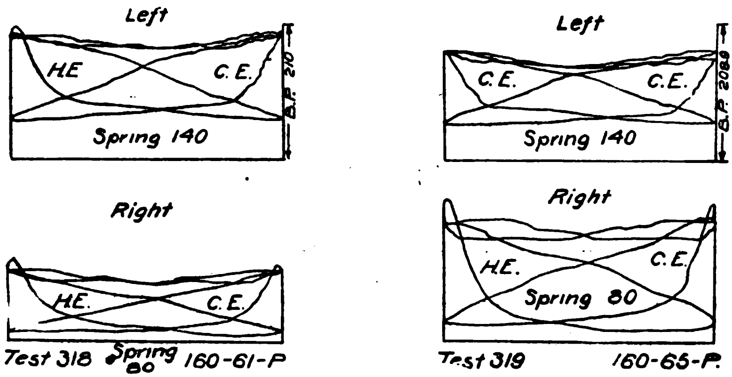
Plot No. 349.



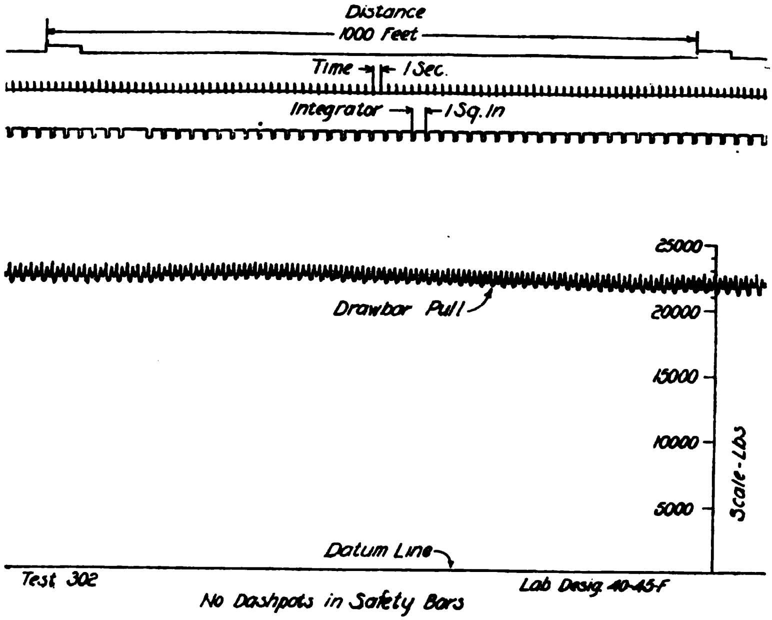
Typical Indicator Diagrams, Locomotive No. 585.



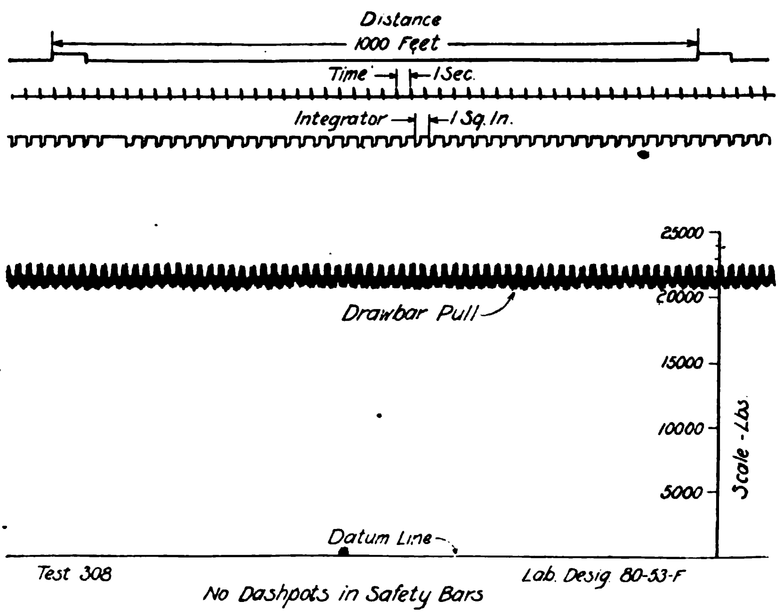
Typical Indicator Diagrams, Locomotive No. 585.



Typical Indicator Diagrams, Locomotive No. 585.

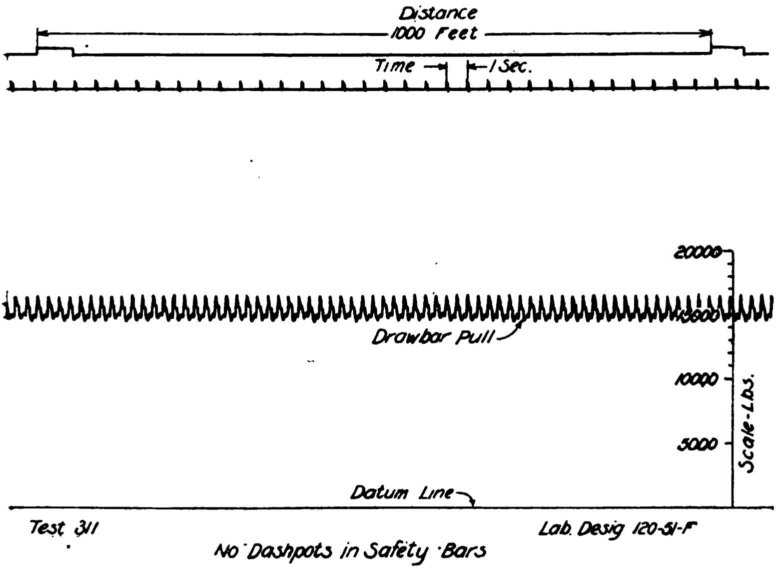


Speed, 7.49 Miles per Hour.

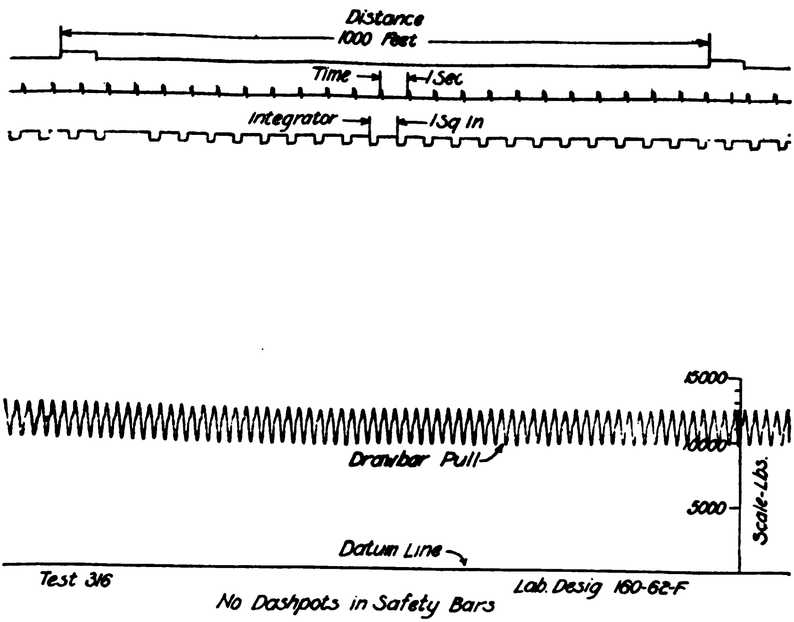


Speed, 14.98 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 585.



Speed, 22.09 Miles per Hour.



Speed, 29.96 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 585.

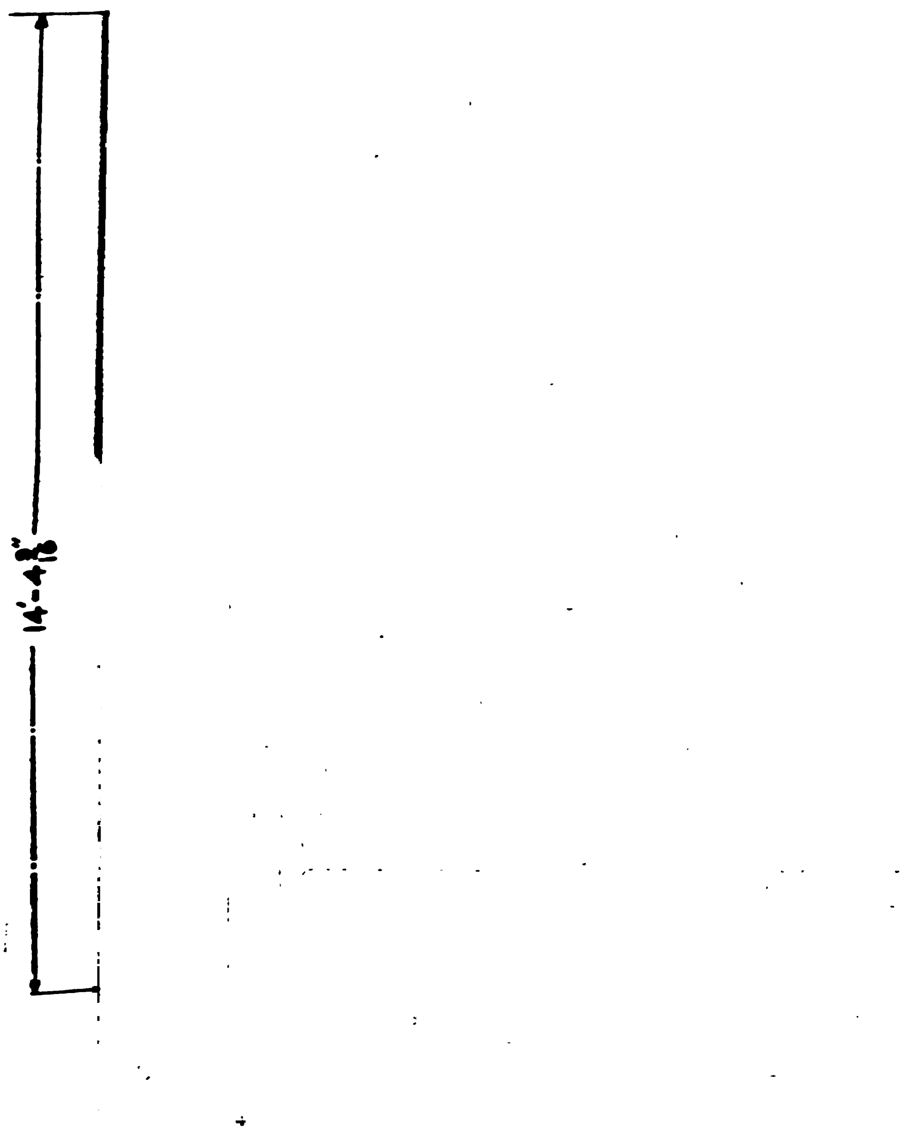


Fig. 213

CHAPTER XVI.

TESTS OF "SANTA FE" TYPE LOCOMOTIVE, ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

The fourth locomotive tested was No. 929, owned by the Atchison, Topeka & Santa Fe Railway System and built at the Baldwin Locomotive Works. It was of the 2-10-2 type and known as class 900 according to the railroad company's classification. It was a four-cylinder tandem compound.

This locomotive occupied the time from August 28 to Septem 17. In these twenty-one working days nine tests were run, the throttling tests being omitted as it was decided that the information would not be valuable on compound locomotives.

Four days were lost on account of difficulties with the plant, one on account of difficulties with the locomotive, and eight and one half days due to trouble experienced in getting the locomotive to the plant.

An accident reduced the number of available brakes to seven, which was unfortunate, as this locomotive was very powerful, and, with the low and varying water pressure in the mains during the period of the tests, it was possible to make tests only at powers below the full capacity of the locomotive. Its calculated tractive power was 63,612 pounds and the highest draw-bar pull obtained in any test was 32,532 pounds.

The critical speed was found to be 96 revolutions, and tests were, therefore, only run at 40, 60 and 80 revolutions per minute. They were not, therefore, complete, nor conclusive, as the limits of the boiler capacity could not be ascertained.

The principal dimensions and the details of the locomotive are given in Appendix 400. The principal nominal dimensions are shown in the following table:

Total weight, pounds	285,740
Weight on drivers, pounds	233,760
Cylinders (Compound), inches	19 & 32 x 32
Diameter of drivers, inches	56.5
Fire-box heating surface, square feet	216.36
Heating surface in tubes (water side) square feet	4601.00
Total heating surface (based on water side of tubes), square feet	4817.36
*Total heating surface (based on fire side of tubes), square feet	4306.13
Grate area, square feet	58.41
Boiler pressure, pounds	225
Valves	Piston
Link motion	Stephenson
Fire-box, type	Radial Stay
Number of tubes	393
Outside diameter of tubes, inches	2.25
Length of tubes, inches	238.5

The maximum tractive effort was 73,177 pounds, working simple, and 63,612 pounds working compound. The ratio of weight on drivers to maximum tractive effort, working simple, was 3.19:1 and when working compound, 3.67:1.

TESTS.

The tests which have been run, together with the laboratory designation and dates of running, are as follows:

TEST NO.	LABORATORY DESIGNATION.	DATE.
401	40-27-F	September 13th.
402	40-35-F	" 14th.
403	40-40-F	" 14th.
405	80-30-F	" 10th.
407	80-40-F	" 12th.
408	80-55-F	" 17th.
410	60-30-F	" 15th.
411	60-35-F	" 16th.
412	60-40-F	" 16th.

* Used in Calculations.

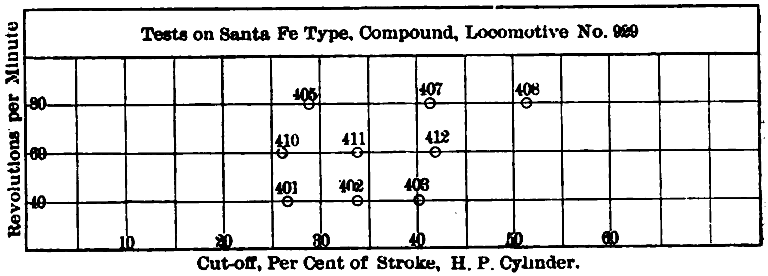


Fig. 401.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 401.

For the reasons explained above, the tests of this locomotive, with relation to the evaporation of the boiler, cannot be regarded as conclusive. The limit of evaporation was not apparently reached in any of the tests.

The tests are arranged in order, according to the rate of equivalent evaporation. All of the tests were of 180 minutes duration and are plotted.

The lowest average boiler pressure was 213 pounds, while the highest was 216.7 pounds. The average temperature of the

TABLE No. 401—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. of Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
401	40-27-F	180	215.4	14.455	77.2	73.1	57.67
402	40-35-F	180	213.5	14.590	65.3	72.3	75.72
410	60-30-F	180	214.1	14.683	59.8	70.4	74.42
403	40-40-F	180	213.5	14.577	60.7	71.8	90.62
405	80-30-F	180	214.2	14.421	84.3	72.8	86.36
411	60-35-F	180	216.3	14.513	64.6	70.9	100.29
412	60-40-F	180	216.7	14.476	76.0	71.5	123.32
407	80-40-F	180	213.0	14.569	68.5	72.3	137.32
408	80-55-F	180	213.5	14.455	78.4	70.8	223.06

feed water did not vary more than 2.7 degrees during the tests of this locomotive.

The total coal fired per square foot of grate area follows:

In 5 tests .... between 50 and 100 pounds.
In 3 tests .... between 100 and 150 pounds.
In 1 test .... more than 200 pounds.

EVAPORATION—TABLE 402.

The evaporation per hour was between the limits of 10,893 pounds and 31,877 pounds.

In general, the quality of the steam in the dome was high,

TABLE No. 402—EVAPORATION.

Identification of Test		Duration of Test, Minutes	Water and Steam		Calorimeter Results			Equivalent Evaporation Lbs. Per Hour
Test Number	Laboratory Designation		Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Quality of steam in Branch Pipe	Degrees Superheat in Branch Pipe	
		Cal.	264	340	*228	229	230	344
401	40-27-F	180	32679	10893	.9839	.9821	0	12926
402	40-35-F	180	39707	13236	.9831	.9814	0	15705
410	60-30-F	180	41257	13752	.9836	.9817	0	16350
403	40-40-F	180	46127	15376	.9835	.9790	0	18273
405	80-30-F	180	46518	15506	.9846	.9821	0	18414
411	60-35-F	180	50899	16966	.9842	.9808	0	20195
412	60-40-F	180	60103	20034	.9843	.9822	0	23814
407	80-40-F	180	70500	23500	.9843	.9807	0	27901
408	80-55-F	180	95630	31877	.9445	.9444	0	36813

but when an evaporation of 30,000 pounds per hour was exceeded the moisture in the steam showed a large increase, indicating that excessive priming began at this point, which is below the probable limit of evaporation. This was possibly due to the fact that the steam dome is low and the throttle valve close to the water surface. It is probable that this boiler could easily evaporate 10 pounds of water per square foot of heating surface, or a total of 43,000 pounds per hour.

BOILER POWER—TABLE 403.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 221.3 to 630.2.

TABLE No. 403—BOILER POWER.

Identification of Test		Duration of Test, Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft. of Grate Surface
		Cal.	Cal.	345	349	Cal.	Cal.
401	40-27-F	180	221.3	3.00	374.7	.087	6.42
402	40-35-F	180	268.9	3.65	455.2	.106	7.79
410	60-30-F	180	279.9	3.80	473.9	.110	8.11
403	40-40-F	180	312.8	4.24	529.6	.123	9.07
405	80-30-F	180	315.3	4.28	533.8	.124	9.14
411	60-35-F	180	345.8	4.69	585.3	.136	10.03
412	60-40-F	180	407.7	5.53	690.3	.160	11.82
407	80-40-F	180	477.7	6.48	808.7	.188	13.84
408	80-55-F	180	630.2	8.55	1067.0	.248	18.27

The equivalent evaporation per square foot of heating surface ranged from 3.00 to 8.55 pounds per hour.

The maximum boiler horse power developed was 1067.0, the horse power being calculated on the usual basis.

The boiler horse power developed per square foot of heating surface ranged from .087 to .248.

The maximum boiler horse power developed per square foot

TABLE No. 404—COAL AND RATE OF COMBUSTION.

Identification of Test		Duration of Test, Minutes	Total Dry Coal Fired	Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation			Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour.	Dry Coal Per Sq. Ft. of Grate Per Hour	Dry Coal Per Sq. Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
401	40-27-F	180	3334	3130	1111	1043	19.03	.258
402	40-35-F	180	4394	4122	1465	1374	25.08	.340
410	60-30-F	180	4310	3999	1437	1333	24.60	.334
403	40-40-F	180	5254	4935	1751	1645	29.98	.407
405	80-30-F	180	4999	4636	1666	1545	28.44	.387
411	60-35-F	180	5805	5440	1935	1813	33.13	.449
412	60-40-F	180	7143	6750	2381	2250	40.77	.553
407	80-40-F	180	7953	7458	2651	2486	45.39	.616
408	80-55-F	180	12897	12133	4299	4044	73.61	.998

of grate surface is equivalent to about one horse power for each .055 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 404.

The total coal fired ranged from 3,334 pounds to 12,897 pounds, and the amount per hour from 1,111 pounds to 4,299 pounds.

TABLE No. 405—CINDERS AND SPARKS.

Identification of Test		Duration of Test, Minutes	Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation		Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
401	40-27-F	180	12.7	40.7	53.3	10784	8143
402	40-35-F	180	8.0	14.0	22.0	10784	7923
410	60-30-F	180	6.0	17.3	23.3	10784	7703
403	40-40-F	180	11.7	24.3	36.0	11004	8804
405	80-30-F	180	18.3	22.0	40.3	11004	9244
411	60-35-F	180	9.3	25.0	34.3	11445	9023
412	60-40-F	180	8.7	47.0	55.7	11445	9244
407	80-40-F	180	17.3	55.3	72.7	11224	8584
408	80-55-F	180	13.0	195.0	208.0	12825	11225

The dry coal fired per square foot of grate area per hour ranged from 19.03 pounds to 73.61 pounds. The increase in the rate of combustion was not regular.

The coal fired per square foot of heating surface per hour ranged from .258 to .998 pounds.

CINDERS AND SPARKS—TABLE 405.

The maximum calorific value of the cinders was 12,325 B. T. U., and the maximum calorific value of the sparks was 11,225 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 406.

The equations which have been obtained by the processes described in detail in Chapter XIII, are given below.

$D = .044\,G$ .... (401)

$T_f = 5.79G + 1520$ .... (402)

$T_s = 2.43\,G + 402$ .... (403)

$T_f - T_s = 3.36G + 1118$ .... (404)

$H = .107\,G + 1.13$ .... (405)

$G = .298\,(T_f - T_s) - 332.7$ .... (406)

$G = 9.35\,H - 10.5$ .... (407)

$H = .0318\,(T_f - T_s) - 34.48$ .... (408)

The fire-box temperatures ranged from 1,507 to 1,932 degrees Fahrenheit, and the smoke-box temperatures from 419 to 574 degrees Fahrenheit. At all rates of combustion, the difference between the fire-box and smoke-box temperatures was nearly constant.

TABLE No. 406—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water				Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In Front of Diaphragm	Back of Diaphragm	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	223	224	225	212	207	339
401	40–27–F	180	.51	.33	.24	.08	1507	419	19.03
402	40–35–F	180	.63	.57	.34	.08	1646	471	25.08
410	60–30–F	180	.72	.65	.42	.10	1684	480	24.60
403	40–40–F	180	.91	.68	.41	.11	1642	486	29.98
405	80–30–F	180	1.06	.73	.54	.00	1936	473	28.44
411	60–35–F	180	1.95	1.81	.42	.11	1737	499	33.13
412	60–40–F	180	1.63	1.37	.68	.31	1737	497	40.77
407	80–40–F	180	2.29	1.45	.99	.39	1811	540	45.39
408	80–55–F	180	3.68	3.25	1.28	.62	1932	574	73.61

EVAPORATIVE PERFORMANCE—TABLE 407.

The equivalent evaporation per pound of dry coal ranged from 8.56 pounds to 11.63 pounds.

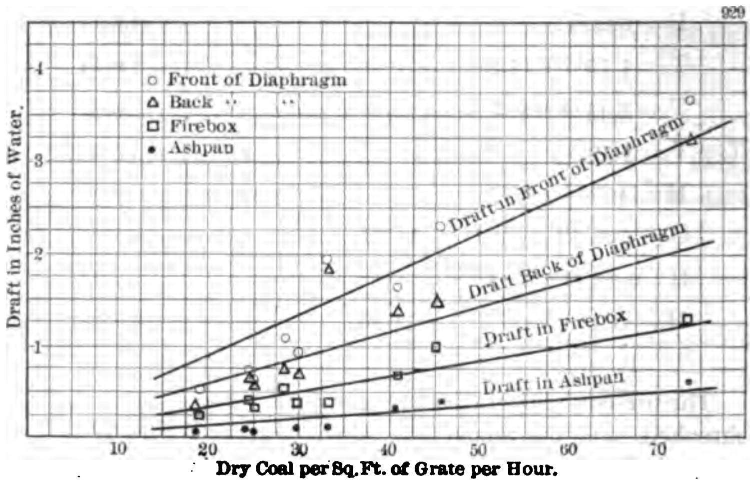


Fig. 402.—Draft and Rate Combustion.

The heating value of the coal was practically uniform for all the tests.

As the rate of evaporation increased the efficiency of the boiler changed but little (if test No. 408 is not included)—the

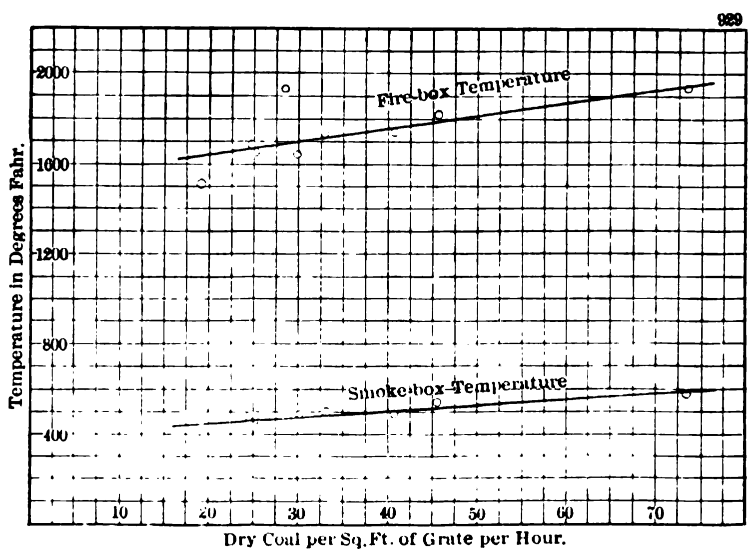


Fig. 403.—Fire-box and Smoke-box Temperatures.

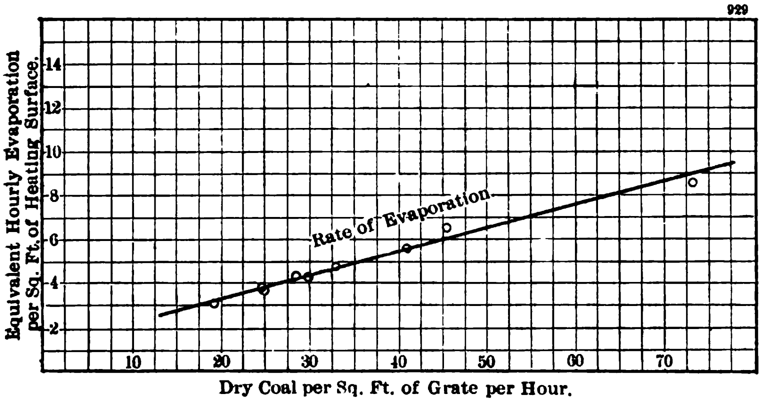


Fig. 404.— Rates of Combustion and Evaporation.

range being between the limits of 74.62 per cent. and 54.69 per cent. The efficiency did not vary directly with the rate of evaporation, but shows some irregularities.

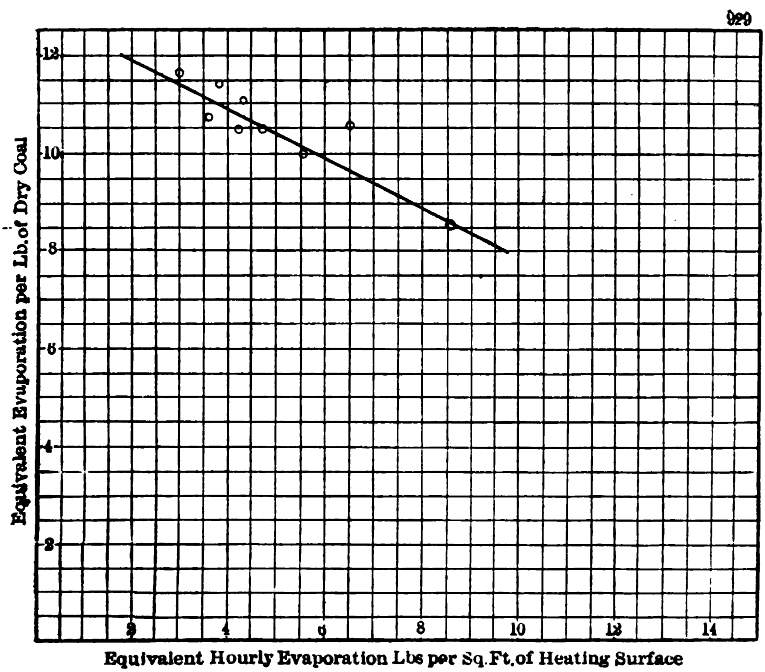


Fig. 405.— Rate of Evaporation and Evaporation per Lb. of Coal.

TABLE No. 407—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
401	40–27–F	180	9.70	11.63	12.39	15117	74.31
402	40–35–F	180	8.98	10.72	11.48	14960	69.23
410	60–30–F	180	9.49	11.38	12.27	14731	74.62
403	40–40–F	180	8.72	10.43	11.11	15077	66.82
405	80–30–F	180	9.22	11.05	11.91	14879	71.75
411	60–35–F	180	8.69	10.44	11.14	14991	67.24
412	60–40–F	180	8.34	10.00	10.58	15203	63.55
407	80–40–F	180	8.79	10.52	11.22	14982	67.80
408	80–55–F	180	7.34	8.56	9.10	15120	54.69

From Fig. 405 the relation between H and E was found to be:

$$E = 12.94 - .507\ H \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (409)$$

SMOKE-BOX GASES—TABLE 408.

The percentage of oxygen shows irregularities, the range for the several tests being between the limits of 12.50 per cent. and 3.87 per cent.

TABLE No. 408—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
401	40–27–F	180	5.67	.23	13.40	80.70	14966	.96
402	40–35–F	180	12.50	.13	6.93	80.44	14856	1.06
410	60–30–F	180	5.67	.20	12.93	81.20	14636	.89
403	40–40–F	180	7.43	.23	11.80	80.54	14966	1.09
405	80–30–F	180	12.13	.30	7.33	80.24	14746	2.28
411	60–35–F	180	3.87	1.57	12.60	81.97	14856	.64
412	60–40–F	180	8.43	.40	10.03	81.14	15076	2.17
407	80–40–F	180	8.67	.23	10.10	81.00	14856	1.28
408	80–55–F	180	5.50	1.23	11.43	81.84	14966	.55

TABLE No. 409—GENERAL ENGINE CONDITIONS.

Identification of Test		Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke H. P. Cylinder	Steam Pressure	
Test Number	Laboratory Designation					In Boiler Lbs. Per Sq. In.	In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	217	220
401	40–27–F	180	40.01	6.72	26.6	215.4	211.2
402	40–35–F	180	40.00	6.72	33.9	213.5	208.8
403	40–40–F	180	39.97	6.71	40.8	213.5	208.8
410	60–30–F	180	60.00	10.08	26.1	214.1	209.7
411	60–35–F	180	60.00	10.08	33.7	216.3	211.5.
412	60–40–F	180	60.64	10.18	41.9	216.7	211.8
405	80–30–F	180	80.00	13.44	28.8	214.2	210.2
407	80–40–F	180	80.00	13.44	41.4	213.0	208.0
408	80–55–F	180	81.28	13.65	51.4	213.5	206.3

In general, the percentage of CO increased as the rate of evaporation increased—the range for this locomotive being between the limits of .13 per cent. and 1.57 per cent.

The carbon dioxide, CO_2, ranged from 6.93 per cent. to 12.93 per cent.

The heat lost by imperfect combustion ranged from .89 per cent. to 2.28 per cent.

TABLE No. 410—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test		Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch		Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
Test Number	Laboratory Designation		H. P. Cyl.	L. P. Cyl.		
		Cal.	Cal.	Cal.	379	381
401	40–27–F	180	39.85	23.92	391.6	26.47
402	40–35–F	180	54.74	30.22	510.8	24.80
403	40–40–F	180	68.49	37.32	633.6	23.38
410	60–30–F	180	37.65	19.76	511.3	25.80
411	60–35–F	180	53.01	26.87	705.2	23.22
412	60–40–F	180	66.60	33.38	888.8	21.84
405	80–30–F	180	31.69	19.43	631.4	23.67
407	80–40–F	180	61 22	31.17	1088.8	20.98
408	80–55–F	180	79.81	31.79	1257.9	24.04

PERFORMANCE OF ENGINES.

As previously noted in other chapters, the results in Tables 409 and 410 are arranged with reference to the speed of the locomotive, the tests at each speed being grouped. The tests in each group are arranged with reference to the nominal cut-off in the high pressure cylinders, the first test in each group being at the shortest cut-off and the last test being at the longest cut-off.

GENERAL ENGINE CONDITIONS—TABLE 409.

The lowest speed at which any test was run was 6.72 miles

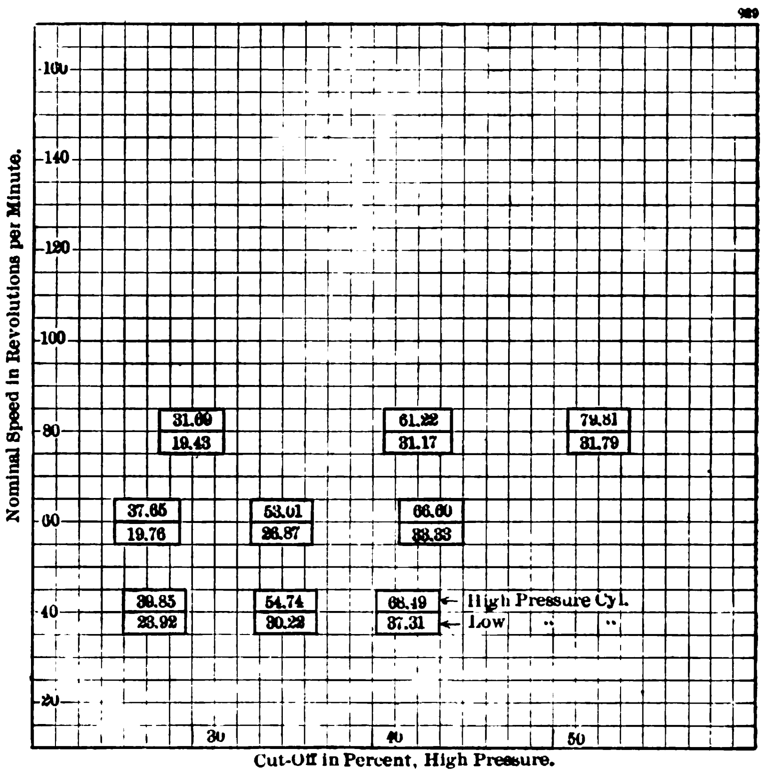


Fig. 406.— Mean Effective Pressure.

per hour, while the highest was 13.65 miles per hour, and the critical speed, as already stated, was 96 revolutions per minute.

It was found that without making some provision for absorbing the longitudinal vibrations of the locomotive it was not practicable to run at speeds much above 80 revolutions, and in order to make the data more complete tests were run at 60 revolutions per minute. While it has been shown that higher speeds would have

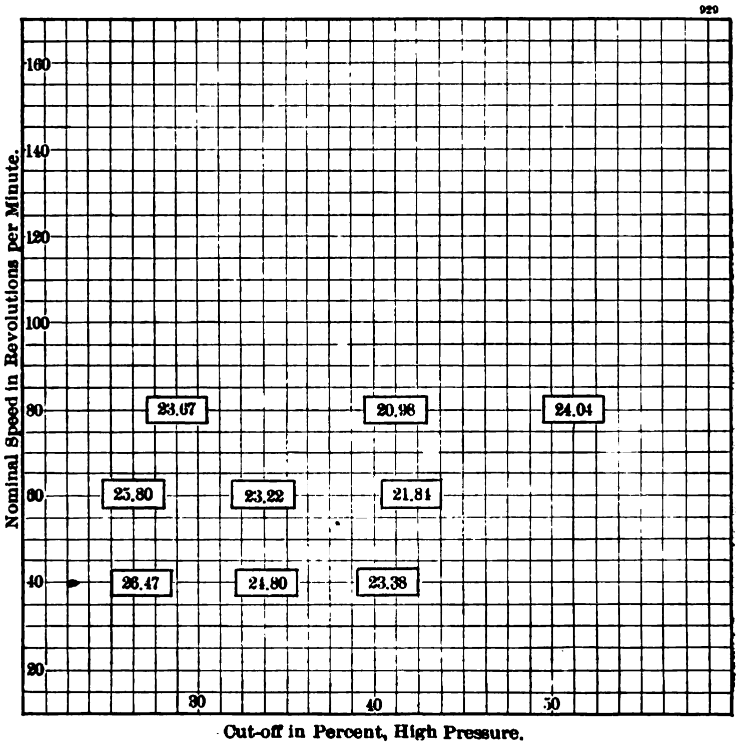


Fig. 407.—Dry Steam per I. H. P. Hour.

been of interest, those at which the locomotive was run fairly cover the range for such a heavy, slow speed locomotive.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 410.

The mean effective pressure, the total indicated horse power and the steam consumption, respectively, for the several high pressure cut-offs and speeds, is shown by Figs. 406, 407, and 408.

The best performance of the engines was at 41.4 per cent. cut-off and 80.0 revolutions per minute (about 13 miles per hour), under which conditions the steam consumption was 20.98 pounds per indicated horse power hour. No throttling tests were run with this locomotive.

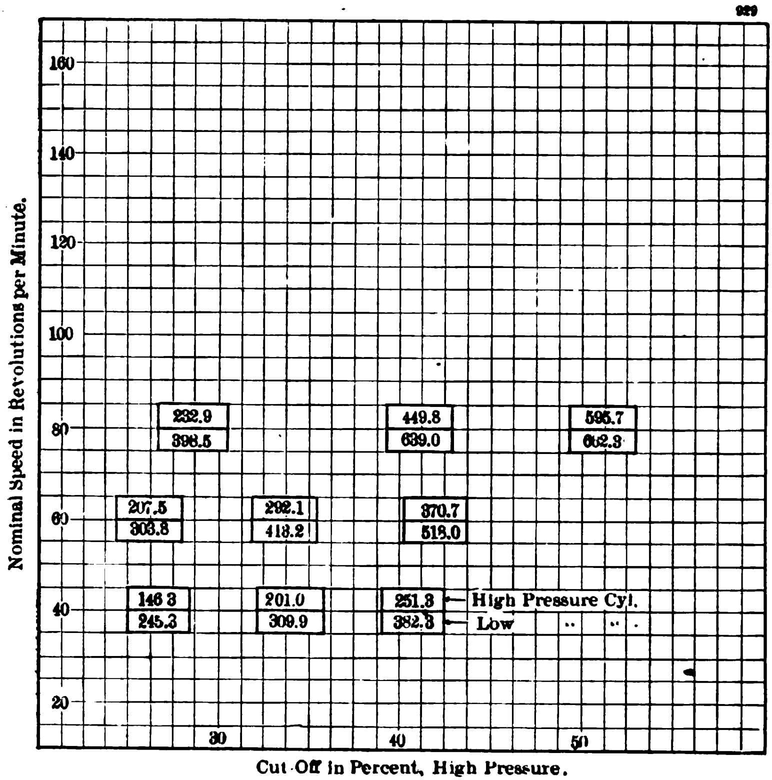


Fig. 408.— Total Indicated Horse Power.

The highest indicated horse power was 1257.9, which was obtained at 51.4 per cent. high pressure cut-off and a nominal speed of 80 revolutions per minute.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 411.

The maximum average recorded draw-bar pull was 31,240 pounds at a nominal speed of 80 revolutions per minute and a high pressure cut-off of 51.4 per cent.

The maximum dynamometer horse power was 1,136.2, which was obtained at a nominal speed of 80 revolutions per minute and a high pressure cut-off of 51.4 per cent.

TABLE No. 411—DYNAMOMETER RECORDS.

Identification of Test		Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D. H. P. Hour
Test Number	Laboratory Designation					
		Cal.	265	383	384	385
401	40–27–F	180	18680	334.6	3.20	30.97
402	40–35–F	180	24784	443.9	3.20	28.53
403	40–40–F	180	31131	557.3	3.06	26.58
410	60–30–F	180	15285	410.7	3.39	32.12
411	60–35–F	180	22279	598.6	3.16	27.36
412	60–40–F	180	29005	787.6	2.96	24.65
405	80–30–F	180	14224	509.6	3.19	29.33
407	80–40–F	180	26929	964.7	2.70	23.68
408	80–55–F	180	31240	1136.2	3.74	26.60

The minimum coal rate obtained was 2.70 pounds and the maximum rate was 3.74 pounds per horse power hour.

The lowest steam consumption was 23.68 pounds per dynamometer horse power hour, which was obtained at a nominal speed

TABLE No. 412—MACHINE FRICTION.

Identification of Test		Duration of Test, Minutes	Machine Friction in		Machine Efficiency Per Cent.
Test Number	Laboratory Designation		Horse Power	Draw-Bar Pull Pounds	
		Cal.	395	397	398
401	40–27–F	180	56.97	3740	85.45
402	40–35–F	180	66.91	3735	86.91
403	40–40–F	180	76.35	4265	87.95
	Average		**66.74**	**3913**	
410	60–30–F	180	100.62	3744	80.33
411	60–35–F	180	106.61	3747	84.88
412	60–40–F	180	101.20	3726	88.61
	Average		**102.81**	**3739**	
405	80–30–F	180	121.77	3399	80.71
407	80–40–F	180	124.11	3464	88.60
408	80–55–F	180	119.70	3889	90.48
	Average		**121.86**	**3584**	

of 80 revolutions per minute and a high pressure cut-off of 41.4 per cent.

The most economical cut-offs at speeds of 40 and 60 revolutions respectively, were not determined, as tests at cut-offs longer than those obtained gave draw-bar pulls beyond the capacity of the brakes with the low water pressure in the service mains.

MACHINE FRICTION—TABLE 412.

The machine efficiency ranged from 80.33 per cent. to 90.48 per cent. While the speeds were low, these figures appear remarkably high for a locomotive having so many journals and moving parts. The small amount of work absorbed in friction is probably due to the fact that while there is a multiplicity of parts the unit loads are low.

MAXIMUM POWER OF LOCOMOTIVE.

As already stated, the maximum evaporation of this boiler was not reached in any of the tests, and, therefore, no attempt was made to predict the maximum draw-bar pull at different speeds.

APPENDIX 400.

The appendix contains:

1. Description, dimensions and proportions of the locomotive. (pp. 348 to 353 inclusive.)

2. Summary of average results of tests. (pp. 354 to 364 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 365 to 369 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 370 to 385 inclusive.)

5. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 386 to 388 inclusive.)

6. A typical dynamometer diagram for each nominal speed. (pp. 389 and 390.)

7. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of A. T. & S. F. Ry. "Santa Fe" (2-10-2) Type Locomotive No. 929.

Built by the Baldwin Locomotive Works, Philadelphia, Pa., 1903.

	DRIVING WHEELS.	
1	Number of pairs	5
2	Approximate diameter, inches	56.5
	MEASURED CIRCUMFERENCE, FEET.	
3	Right, No. 1	14.784
4	" " 2	14.777
5	" " 3	14.790
6	" " 4	14.768
7	" " 5	14.781
8	Left, " 1	14.783
9	" " 2	14.768
10	" " 3	14.780
11	" " 4	14.774
12	" " 5	14.788
13	Average	14.779
	ENGINE TRUCK WHEELS.	
14	Number	2
15	Diameter, inches	28.5
	TRAILING WHEELS.	
16	Diameter, inches	39.9
	WHEEL BASE, FEET.	
17	Driving wheel base	19.768
18	Total wheel base	35.885
19	Gauge of wheels, in inches	55.875
	WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.	
20	On truck	25,860
21	" 1st drivers	53,110
22	" 2nd "	58,100
23	" 3rd "	45,760
24	" 4th "	36,110
25	" 5th "	40,680
26	" trailers	26,120
27	Total	285,740
28	" on drivers	233,760
	CYLINDERS.	
29	High pressure, number	2
30	Low " "	2
31	Arrangement	Outside, tandem compound

DIAMETER, INCHES.

32	High	pressure,	right	19.129
33	"	"	left	19.165
34	Low	"	right	32.000
35	"	"	left	32.000

STROKE OF PISTON, FEET.

36	High	pressure,	right	2.671
37	"	"	left	2.668
38	Low	"	right	2.671
39	"	"	left	2.668

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P.,	right,	head	end	17.217
41	"	"	crank	"	17.111
42	"	left,	head	"	17.172
43	"	"	crank	"	17.064
44	L. P.,	right,	head	"	8.275
45	"	"	crank	"	8.458
46	"	left,	head	"	8.284
47	"	"	crank	"	8.467

RECEIVER, CUBIC FEET.

48	Volume,	right	side	} —
49	"	left	"	}

STEAM PORTS, INCHES.

(For piston valves the length equals the circumference of inside of bushing minus the sum of the widths of bridges.)

50	H. P.	admission,	right,	head	end,	length	29.56
51	"	"	"	"	"	width	1.625
52	"	"	"	crank	"	length	29.56
53	"	"	"	"	"	width	1.625
54	"	"	left,	head	"	length	30.82
55	"	"	"	"	"	width	1.625
56	"	"	"	crank	"	length	30.82
57	"	"	"	"	"	width	1.625
58	L. P.	"	right,	head	"	length	28.03
59	"	"	"	"	"	width	1.75
60	"	"	"	crank	"	length	28.03
61	"	"	"	"	"	width	1.75
62	"	"	left,	head	"	length	33.05
63	"	"	"	"	"	width	1.75
64	"	"	"	crank	"	length	33.05
65	"	"	"	"	"	width	1.75
66	H. P.	exhaust,	right,	length			40.91
67	"	"	"	width			3.25
68	"	"	left,	length			40.97
69	"	"	"	width			3.25
70	L. P.	"	right,	length			28.03

71	L. P. exhaust, right, width	6.25
72	" " left, length	33.05
73	" " " width	6.25

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	3.250
75	" " left	3.250
76	Low " right	4.461
77	" " left	4.461

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	" " left	——
80	Low " right	3.25
81	" " left	3.25

VALVES.

82	Type	Piston
83	Design,	Baldwin Locomotive Works
84	Per cent. of balanced to total area	H. P. 72.5; L. P. 85.1
85	Type of link motion,	Stephenson, open rods

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	5.25
87	" " left	5.25
88	Low " right	5.25
89	" " left	5.25

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure, right, head end	.875
91	" " " crank "	.875
92	" " left, head "	.875
93	" " " crank "	.875
94	Low " right, head "	.750
95	" " " crank "	.750
96	" " left, head "	.750
97	" " " crank "	.750

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	negative	.250
99	" " " crank "	"	.250
100	" " left, head "	"	.250
101	" " " crank "	"	.250
102	Low " right, head "	"	.375
103	" " " crank "	"	.375
104	" " left, head "	"	.375
105	" " " crank "	"	.375

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	iron .069 thick
108	Lead, forward motion,	H. P., 0; L. P., .125
109		
110		
111		
112	Right crank leads	

BOILER.

113	Type	Wagon top, radial stay, wide fire box
114	Outside diameter, 1st ring, inches	81.05

TUBES.

115	Number	393
116	Outside diameter, inches	2.250
117	Thickness, inches	.125
118	Length between tube sheets, inches	238.500
119	Total fire area, square feet	8.570
120	Serve tubes, number of ribs	——
121	" " sq. in. of inside surface in one in. of length	——
122		
123		
124	Boiler pressure, pounds per sq. inch,	225

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129		
130		
131		

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	104.25
133	Width	77.88
134	Depth, front end	74.50
135	" back "	72.50
136	Volume, cubic feet	313.10
137	Air inlets to ash pan, (dampers closed) sq. ft.	0.00
138	" " " " " (" open) " "	7 44
139		
140		

FIRE DOORS.

141	Number	2
142	Area, square feet (of both)	3.49
143		

GRATES.

144	Style	rocking finger
145	Total area, square feet	58.41
146	" " dead grates, square feet	0
147	Width of air spaces, inches	.94

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	0
149	" grates	22.160
150	" fire doors	.030
151	Total air inlets, (148), (149) and (150)	22.190
152	Ratio " " (149) to grate area (145)	.379
153	" " " (151) " " " (145)	.380

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	4601.00
155	" " " fire "	4089.77
156	" " firebox, fire side	216.36
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	4306.13
159	Total, based on inside of firebox and outside of tubes	4817.36

BOILER VOLUMES.

(With water surface at level of second gauge cock.)

160	Water space, cubic feet	562.8
161	Steam " "	94.6

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	6
164	" " left, "	
165	Area of right, square inches	——
166	" " left, " "	——
167	Total area, square inches	28.274

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	19
169	L. P. " " " " "	
170		

RATIOS.

171	Heating surface (158) to grate area (145)......	73.73
172	Fire area through tubes (119) to grate area (145)	.15
173	Firebox heating surface (156) to grate area (145)	3.70
174	Tube surface (155) to firebox heating surface (156)..	18.90
175	Firebox volume (136) to grate area (145)......	5.36
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(*power developed at one R. P. M. when pull is one pound.*)

179	....	.0004478

CONSTANTS FOR INDICATED HORSE POWER

(*power developed at one R. P. M. and one pound M. E. P.*)

180	High	pressure	cylinder,	right,	head	end	.02326
181	"	"	"	"	crank	"	.02259
182	"	"	"	left,	head	"	.02332
183	"	"	"	"	crank	"	.02265
184	Low	"	"	right,	head	"	.06442
185	"	"	"	"	crank	"	.06383
186	"	"	"	left,	head	"	.06435
187	"	"	"	"	crank	"	.06376

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head	end	5.330
189	"	"	"	"	crank	"	5.177
190	"	"	"	left,	head	"	5.344
191	"	"	"	"	crank	"	5.191
192	Low	"	"	right,	head	"	14.762
193	"	"	"	"	crank	"	14.627
194	"	"	"	left,	head	"	14.746
195	"	"	"	"	crank	"	14.611

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed: Revolutions: Total	Speed: Revolutions: Average Per Minute	Speed: Equivalent: Speed in Miles Per Hour	Speed: Equivalent: Piston Speed in Feet Per Minute	Position of Levers: Reverse, Notches From Front End	Position of Levers	Position of Levers: Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	
		196	197	198	199	200	201	202	203	204	205
401	40–27–F	3	7201	40.006	6.719	213.58	16		Full	42	
402	40–35–F	3	7200	40.000	6.718	213.55	15		"	46	
403	40–40–F	3	7195	39.972	6.714	213.41	14		"	45	
405	80–30–F	3	14400	80.000	13.435	427.13	16		"	43	
407	80–40–F	3	14400	80.000	13.435	427.13	14		"	45	
408	80–55–F	3	14631	81.283	13.652	434.00	13		"	55	
410	60–30–F	3	10800	60.000	10.077	320.34	16		"	43	
411	60–35–F	3	10800	60.000	10.077	320.34	15		"	46	
412	60–40–F	3	10915	60.639	10.184	323.75	14		"	48	

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of: Smoke Box: By Thermometer	Smoke Box: By Pyrometer	Laboratory: Dry Bulb	Laboratory: Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer				Steam lost from Boiler, etc. Lbs. per hour
		206	207	208	209	210	211	212	213	214	215	216
401	40–27–F	458	419	77.2	69.0	392.0	73.1	1507				408
402	40–35–F	467	471	65.3	55.1	391.2	72.3	1646				412
403	40–40–F	482	486	60.7	51.9	391.2	71.8	1642				394
405	80–30–F	491	473	84.3	71.1	391.6	72.8	1936				396
407	80–40–F	547	540	68.5	57.2	390.8	72.3	1811				393
408	80–55–F	577	574	78.4	67.4	390.1	70.8	1932				392
410	60–30–F	489	480	59.8	53.2	391.5	70.4	1684				404
411	60–35–F	501	499	64.6	57.2	386.5	70.9	1737				399
412	60–40–F	514	497	76.0	65.2	392.3	71.5	1737				399

For date of test, see item 407.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	Pressure: In Boiler: Maximum	Pressure: In Boiler: Minimum	Pressure: In Branch Pipe	Pressure: Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box: Front of Diaphragm.	Draft: In Smoke Box: Back of Diaphragm.	Draft: In Fire Box	Draft: In Ash Pan	Injectors: Hours in Action: Total, Right	Injectors: Hours in Action: Total, Left
		217	218	219	220	221	222	223	224	225	226	227
401	40-27-F	215.4	218.5	209.0	211.2	14.455	.51	.38	.24	.08	0	1.27
402	40-35-F	213.5	220.8	210.8	208.8	14.590	.63	.57	.34	.08	0	1.51
403	40-40-F	213.5	216.3	209.0	208.8	14.577	.91	.68	.41	.11	0	1.71
405	80-30-F	214.2	217.5	211.5	210.2	14.421	1.06	.78	.54	.0	0	1.71
407	80-40-F	213.0	216.0	206.3	208.0	14.569	2.29	1.45	.99	.39	0	2.71
408	80-55-F	213.5	219.0	201.5	206.3	14.455	3.68	3.25	1.28	.62	0	2.94
410	60-30-F	214.1	216.5	210.5	209.7	14.633	.72	.65	.42	.10	0	1.37
411	60-35-F	216.3	218.0	213.0	211.5	14.518	1.95	1.81	.42	.11	0	1.83
412	60-40-F	216.7	220.2	214.1	211.8	14.476	1.63	1.37	.68	.31	0	2.12

Test Number	Laboratory Designation	Quality of steam: In Dome	Quality of steam: In Branch Pipe	Quality of steam: Degrees of Superheat in Branch Pipe	Quality of steam: Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Coal Fired: Kind	Coal Fired: Total	Coal Fired: Per Cent of Moisture	Total: Dry Coal Fired	Total: Combustible by Analysis	Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
401	40-27-F	.9839	.9821	0	.98843	Bituminous	3368	1.00	3334	3130	204
402	40-35-F	.9831	.9814	0	.98784	"	4423	.70	4394	4122	270
403	40-40-F	.9835	.9790	0	.98811	"	5293	.74	5254	4935	318
405	80-30-F	.9846	.9821	0	.98895	"	5044	.90	4999	4636	362
407	80-40-F	.9843	.9807	0	.98866	"	8021	.84	7953	7458	494
408	80-55-F	.9445	.9444	0	.96012	"	13029	1.02	12897	12133	762
410	60-30-F	.9836	.9817	0	.98821	"	4347	.85	4310	3999	311
411	60-35-F	.9842	.9808	0	.98866	"	5858	.90	5805	5440	366
412	60-40-F	.9843	.9822	0	.98873	"	7204	.84	7143	6750	392

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs. Total: Cinders Collected in Smoke Box	Sparks Discharged From Stack	Cinders and Sparks	Analysis of Coal, Per Cent: Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
401	40-27-F	38	122	160	75.83	17.12	1.00	6.05	1.11		
402	40-35-F	24	42	66	75.94	17.25	.70	6.11	1.03		
403	40-40-F	35	73	108	75.90	17.35	.74	6.01	1.43		
405	80-30-F	55	66	121	74.27	17.65	.90	7.18	1.15		
407	80-40-F	52	166	218	75.39	17.61	.84	6.16	.99		
408	80-55-F	39	585	624	76.10	17.03	1.02	5.85	1.09		
410	60-30-F	18	52	70	74.63	17.36	.85	7.16	1.79		
411	60-35-F	28	75	103	75.37	17.49	.90	6.24	1.07		
412	60-40-F	26	141	167	76.32	17.40	.84	5.44	1.08		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B.T.U.: Of Dry Coal	Of Combustible	Of Cinders	Of Sparks		Analysis of Smoke Box Gases, Per Cent: Oxygen O	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
401	40-27-F	15117	16108	10784	8143		5.67	.23	13.40	80.70		
402	40-35-F	14960	15941	10784	7923		12.50	.13	6.93	80.44		
403	40-40-F	15077	16049	11004	8804		7.43	.23	11.80	80.54		
405	80-30-F	14879	16042	11004	9244		12.13	.30	7.33	80.24		
407	80-40-F	14982	15973	11224	8584		8.67	.23	10.10	81.00		
408	80-55-F	15120	16070	12325	11225		5.50	1.23	11.43	81.84		
410	60-30-F	14731	15910	10784	7703		5.67	.20	12.93	81.20		
411	60-35-F	14991	15999	11445	9023		3.87	1.57	12.60	81.97		
412	60-40-F	15203	16086	11445	9244		8.43	.40	10.03	81.14		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

ATCHISON, TOPEKA AND SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Water, in Pounds						Dynamometer		
			Lost					Drawbar Pull in Pounds		
		Delivered to Injectors	From Boiler	From Injectors	From	Total	Delivered to Boiler and Presumably Evaporated	Average	Maximum	Minimum
		259	260	261	262	263	264	265	266	267
401	40–27–F	32679	0	0		0	32679	18680	19200	17800
402	40–35–F	39707	0	0		0	39707	24784	25655	24200
403	40–40–F	46127	0	0		0	46127	31131	32100	29998
405	30–30–F	46518	0	0		0	46518	14224	14788	13750
407	30–40–F	70500	0	0		0	70500	26929	27398	25930
408	30–55–F	96000	0	370		370	95630	31240	32532	28758
410	60–30–F	41257	0	0		0	41257	15285	15805	14840
411	60–35–F	51249	0	350		350	50899	22279	23126	21498
412	60–40–F	60103	0	0		0	60103	29005	29994	27900

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Cut-off, Per Cent. of Stroke								Release, Per Cent. of Stroke			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
401	40–27–F	26.6	24.5	30.2	25.1	33.2	30.6	33.2	31.7	55.1	52.4	57.2	52.2
402	40–35–F	33.9	31.7	36.4	33.4	39.5	37.5	39.6	38.2	57.9	53.6	59.9	53.0
403	40–40–F	40.9	38.8	43.3	40.2	47.1	44.8	46.2	45.3	63.2	61.1	64.8	62.8
405	30–30–F	29.3	27.2	30.9	27.9	33.9	29.6	31.9	30.8	57.7	49.1	58.6	50.4
407	30–40–F	42.1	39.9	44.3	39.3	44.8	42.8	45.4	43.8	65.1	63.6	67.6	63.9
408	30–55–F	51.7	49.8	54.6	49.3	54.7	51.6	56.2	52.5	72.2	68.4	73.2	69.1
410	60–30–F	26.6	24.2	28.8	24.8	31.8	29.5	31.8	32.1	51.4	48.4	54.7	46.8
411	60–35–F	34.8	31.4	36.8	31.9	39.1	36.0	39.1	36.7	60.3	56.9	62.7	57.0
412	60–40–F	42.6	39.5	45.4	40.2	46.2	43.5	47.1	43.6	62.8	61.3	66.5	61.0

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929, ATCHISON, TOPEKA AND SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards: Release, Per Cent. of Stroke: Low Pressure Cylinder: Right Side: Head End	Release, LP, Right Side: Crank End	Release, LP, Left Side: Head End	Release, LP, Left Side: Crank End	Beginning of Compression, Per Cent. of Stroke: High Pressure Cylinder: Right Side: Head End	Compression, HP, Right Side: Crank End	Compression, HP, Left Side: Head End	Compression, HP, Left Side: Crank End	Compression, Low Pressure Cylinder: Right Side: Head End	Compression, LP, Right Side: Crank End	Compression, LP, Left Side: Head End	Compression, LP, Left Side: Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
401	40-27-F	53.5	51.5	53.6	52.6	27.6	28.2	28.4	28.6	24.7	23.1	23.6	24.1
402	40-35-F	59.5	56.4	58.9	57.6	24.8	23.9	25.2	25.6	21.8	19.8	20.0	20.9
403	40-40-F	65.5	63.4	64.7	63.9	19.9	20.3	20.7	20.3	17.0	16.4	16.3	16.7
405	80-30-F	58.2	54.6	57.2	55.2	28.8	28.0	29.8	27.1	27.3	27.9	28.4	28.2
407	80-40-F	68.5	68.2	69.7	68.3	24.9	24.3	23.8	23.1	24.2	24.6	25.4	23.1
408	80-55-F	69.6	66.4	71.4	67.6	22.8	22.8	23.5	21.7	22.9	19.5	22.1	20.5
410	60-30-F	52.4	49.9	53.0	51.3	28.8	28.2	29.7	27.6	26.6	25.2	25.8	26.3
411	60-35-F	59.8	56.2	61.2	57.9	23.0	23.7	25.8	23.6	24.1	22.2	22.6	24.3
412	60-40-F	68.8	61.3	64.8	61.2	19.7	20.0	21.5	20.4	21.2	20.2	20.3	21.2

Test Number	Laboratory Designation	Pressures from Indicator Cards: Initial Pressures, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	HP, Right Side: Crank End	HP, Left Side: Head End	HP, Left Side: Crank End	Low Pressure Cylinder: Right Side: Head End	LP, Right Side: Crank End	LP, Left Side: Head End	LP, Left Side: Crank End	Factor of Evaporation
		292	293	294	295	296	297	298	299	300
401	40-27-F	217.9	217.5	215.6	216.6	79.4	78.1	82.8	84.7	1.2005
402	40-35-F	214.7	217.0	214.0	213.9	78.1	77.9	87.4	89.2	1.2013
403	40-40-F	213.8	214.7	213.1	215.2	83.4	82.9	88.8	88.8	1.2018
405	80-30-F	222.0	222.5	222.5	221.9	78.9	78.7	79.4	78.6	1.2008
407	80-40-F	212.1	219.4	220.3	217.5	82.3	81.1	83.7	85.1	1.2010
408	80-55-F	215.7	211.4	214.2	209.9	79.1	77.1	84.8	82.9	1.2028
410	60-30-F	214.4	216.4	214.3	214.8	70.6	72.1	78.6	78.7	1.2030
411	60-35-F	220.9	223.6	223.6	220.3	79.2	74.2	83.7	84.3	1.2039
412	60-40-F	218.6	221.5	220.3	215.0	80.3	77.1	89.2	90.1	1.2022

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

ATCHISON, TOPEKA AND SANTA FE RAILWAY SYSTEM.

Test Nnmber	Laboratory Designation	Pressures from Indicator Cards								
		Steam Chest Pressures, Pounds Per Square Inch					Pressures at Cut-off, Pounds Per Square Inch			
		High Pressure		Low Pressure			High Pressure Cylinder			
							Right Side		Left Side	
		Right Side	Left Side	Right Side	Left Side		Head End	Crank End	Head End	Crank End
		301	302	303	304	305	306	307	308	309
401	40-27-F	218.5		83.6			189.8	194.5	188.2	194.5
402	40-35-F	217.0		80.2			182.2	182.1	187.3	188.2
403	40-40-F	217.1		83.2			188.7	189.5	181.6	192.9
405	80-30-F	———		84.5			174.7	165.8	173.9	175.8
407	80-40-F	220.6		86.0			179.8	176.0	179.3	180.9
408	80-55-F	213.1		86.5			177.2	171.9	178.5	175.8
410	60-30-F	217.0		———			180.4	190.7	183.1	184.7
411	60-35-F	218.9		82.2			178.4	185.9	182.8	186.5
412	60-40-F	206.5		84.3			182.1	181.6	178.5	183.9

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Cut-off, Pounds Per Square Inch				Pressures at Release, Pounds Per Square Inch							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
401	40-27-F	47.4	49.1	49.1	58.2	107.3	108.9	117.9	109.9	23.7	23.6	23.6	24.4
402	40-35-F	43.3	46.0	51.1	56.4	119.5	122.0	124.9	127.8	24.0	25.7	27.6	30.5
403	40-40-F	45.0	49.9	51.7	55.2	130.1	129.5	132.2	130.3	27.1	30.1	30.7	33.6
405	80-30-F	41.0	43.7	40.0	43.9	104.4	111.8	104.7	106.9	18.6	19.9	16.9	19.7
407	80-40-F	46.8	45.0	44.1	46.9	121.3	121.2	122.4	121.2	25.8	23.9	23.6	25.4
408	80-55-F	39.6	40.5	43.9	42.0	130.5	123.0	132.8	130.2	29.2	29.7	30.9	30.1
410	60-30-F	39.0	43.1	43.5	45.6	109.5	111.2	115.6	122.0	19.5	23.5	21.4	23.7
411	60-35-F	41.6	45.3	46.5	50.0	112.7	115.8	118.1	118.0	22.9	25.5	24.3	26.8
412	60-40-F	42.3	44.4	48.5	51.9	126.6	126.4	128.4	130.0	27.1	28.2	30.7	33.1

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Beginning of Compression, Pounds Per Square Inch								Least Back Pressure, Pounds Per Square Inch			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
401	40-27-F	101.0	97.6	103.9	105.3	5.0	5.7	5.0	5.6	71.2	72.1	75.8	74.1
402	40-35-F	100.1	96.4	106.3	105.6	5.9	5.8	5.9	6.2	68.6	63.7	76.7	72.8
403	40-40-F	104.6	102.5	106.6	106.7	6.7	6.9	6.8	7.8	69.9	65.9	78.1	70.7
405	80-30-F	104.8	105.2	102.3	103.0	5.9	6.6	6.8	6.8	73.8	74.1	74.4	71.6
407	80-40-F	95.9	100.9	104.9	102.9	8.0	7.1	6.6	8.3	68.6	70.8	74.1	70.5
408	80-55-F	91.6	81.5	90.6	86.8	11.4	7.7	9.2	8.9	64.7	61.8	67.3	66.6
410	60-30-F	97.3	103.1	100.6	102.9	6.2	6.3	6.3	6.4	67.7	66.5	73.8	68.5
411	60-35-F	101.8	101.8	104.3	104.1	7.0	6.8	7.2	6.9	64.8	66.2	72.9	69.2
412	60-40-F	103.6	101.7	108.6	106.4	7.5	7.0	8.1	7.3	66.0	63.7	75.1	70.1

Test Number	Laboratory Designation	Pressures from Indicator Cards				Boiler					
		Least Back Pressure, Pounds Per Square Inch				Dry Coal Fired Pounds		Evaporation, Pounds			
		Low Pressure Cylinder						Steam Per Hour			
		Right Side		Left Side							
		Head End	Crank End	Head End	Crank End	Per Hour	Per Hour Per Square Foot of Grate Surface	Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
401	40-27-F	.6	1.0	.4	.6	1111	19.03	10893	10766	2.500	9.688
402	40-35-F	2.0	1.6	.9	1.8	1465	25.08	13236	13074	3.036	8.927
403	40-40-F	2.0	1.8	1.9	2.0	1751	29.98	15376	15204	3.531	8.682
405	80-30-F	.3	1.8	1.6	1.9	1666	28.44	15506	15334	3.561	9.203
407	80-40-F	3.6	3.6	2.7	2.9	2651	45.39	23500	23232	5.395	8.764
408	80-55-F	7.7	6.3	7.3	6.9	4299	73.61	31877	30603	7.107	7.119
410	60-30-F	1.9	1.8	1.8	1.6	1437	24.60	13752	13590	3.157	9.460
411	60-35-F	.8	1.7	1.4	1.5	1935	33.13	16966	16773	3.895	8.669
412	60-40-F	2.3	2.6	2.2	2.3	2381	40.77	20034	19808	4.600	8.319

For steam lost from boiler and not delivered to engines, see item 216.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Per Hour, Per Sq. Ft. of Heat. Surface	Per Pound of: Coal as Fired	Dry Coal as Fired	Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		344	345	346	347	348	349	350	351	352	353	354
401	40–27–F	12926	3.00	11.51	11.63	12.89	374.7	74.81	37.94	39.70	42.64	39.10
402	40–35–F	15705	3.65	10.65	10.72	11.43	455.2	69.23	53.53	57.71	58.89	58.81
403	40–40–F	18273	4.24	10.36	10.43	11.11	529.6	66.82	65.40	70.50	68.68	69.38
405	80–30–F	18414	4.28	10.95	11.05	11.91	533.8	71.75	30.40	30.37	34.51	31.48
407	80–40–F	27901	6.48	10.44	10.52	11.22	808.7	67.80	63.57	59.37	60.83	61.10
408	80–55–F	36818	8.55	8.48	8.56	9.10	1067.0	54.69	80.07	78.62	81.00	79.55
410	60–30–F	16350	3.80	11.28	11.38	12.27	473.9	74.62	38.41	36.15	40.31	35.72
411	60–35–F	20195	4.69	10.34	10.44	11.14	585.3	67.24	53.36	52.43	53.93	52.31
412	60–40–F	23814	5.53	9.92	10.00	10.58	690.3	63.55	68.06	68.05	64.21	66.06

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square inch: Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Receiver Pressure: Right Side	Receiver Pressure: Left Side	Number of Expansions: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		355	356	357	358	359	360	361	362	363	364
401	40–27–F	23.99	22.64	24.45	24.58			3.90	4.07	2.53	2.19
402	40–35–F	27.02	27.78	32.60	33.49			3.67	3.75	3.46	3.69
403	40–40–F	34.61	36.50	38.25	39.90			3.52	3.63	3.33	3.56
405	80–30–F	20.84	19.47	18.11	19.30			3.96	4.02	3.76	3.99
407	80–40–F	31.91	30.14	30.67	31.95			3.58	3.80	3.50	3.83
408	80–55–F	26.55	32.30	35.25	33.05			3.13	3.17	3.06	3.23
410	60–30–F	17.77	19.56	20.37	21.32			3.84	3.99	3.68	4.02
411	60–35–F	24.30	26.65	27.55	28.97			3.62	3.77	3.55	3.82
412	60–40–F	29.66	31.24	35.52	36.90			3.57	3.48	3.22	3.42

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
401	40-27-F	35.8	35.9	39.8	35.4	61.8	57.8	63.0	62.7	71.2	75.1	119.6	125.7
402	40-35-F	49.8	52.2	50.3	48.8	69.6	70.9	83.9	85.4	102.0	99.0	140.6	169.3
403	40-40-F	60.8	63.7	64.0	62.8	89.1	93.1	98.4	101.7	124.5	126.8	182.2	200.1
405	80-30-F	56.6	54.9	64.4	57.0	107.4	99.4	93.2	98.5	111.5	121.4	206.8	191.7
407	80-40-F	118.3	107.3	113.5	110.7	164.3	153.9	157.9	163.0	225.6	224.2	318.2	320.8
408	80-55-F	151.4	144.4	153.5	146.5	139.0	167.6	184.4	171.3	295.7	300.0	306.6	355.7
410	60-30-F	53.6	49.0	56.4	48.5	68.7	74.9	78.6	81.6	102.6	104.9	143.6	160.2
411	60-35-F	74.5	71.1	75.5	71.1	93.9	102.1	106.4	110.8	145.5	146.6	196.0	217.2
412	60-40-F	96.0	92.2	90.8	90.7	115.9	120.9	138.6	142.7	189.2	181.5	236.8	281.2

Test Number	Laboratory Designation	Engines						Dynamometer Horse Power	Locomotive		
		Division of Power			Consumed Per I. H. P., Hour				Pounds Per D. H. P., Hour		B. T. U. Per D. H. P., Hour
		Total		Total I. H. P.							
		Right Side	Left Side		Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.		Of Dry Coal	Of Dry Steam	
		377	378	379	380	381	382	383	384	385	386
401	40-27-F	190.8	200.8	391.6	2.73	26.47	41280	334.6	3.20	30.97	48305
402	40-35-F	242.5	268.3	510.8	2.78	24.80	41539	443.9	3.20	28.53	47796
403	40-40-F	306.7	326.9	633.6	2.69	23.38	40599	557.3	3.06	26.58	46160
405	80-30-F	318.3	313.1	631.4	2.57	23.67	38255	509.6	3.19	29.33	47402
407	80-40-F	543.8	545.0	1088.8	2.39	20.98	35860	964.7	2.70	23.68	40471
408	80-55-F	602.3	655.6	1257.9	3.37	24.04	51020	1136.2	3.74	26.60	56481
410	60-30-F	246.2	265.1	511.3	2.73	25.80	40157	410.7	3.39	32.12	49997
411	60-35-F	341.5	363.7	705.2	2.68	23.22	40161	598.6	3.16	27.36	47332
412	60-40-F	426.0	462.8	888.8	2.63	21.84	39913	787.6	2.96	24.65	45041

For Maximum Indicated Horse Power, see item 403.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

Atchison, Topeka and Santa Fe Railway System.

Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	I. H. P. Per Square Foot of: Heating Surface	Grate Surface	D. H. P. Per Square Foot of: Heating Surface	Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
401	40–27–F	1.61	15.64	24395	.0909	6.71	.0777	5.73	21770	56.97		3740
402	40–35–F	1.61	14.41	24137	.1186	8.75	.1031	7.60	28400	66.91		3735
403	40–40–F	1.55	13.43	23311	.1471	10.85	.1294	9.54	35250	76.35		4265
405	80–30–F	1.61	14.81	23937	.1466	10.81	.1183	8.72	17550	121.77		3399
407	80–40–F	1.36	11.96	20437	.2529	18.64	.2240	16.52	30270	124.11		3464
408	80–55–F	1.39	13.42	23500	.2921	21.54	.2643	19.49	34417	119.70		3889
410	60–30–F	1.71	16.22	25244	.1187	8.75	.0954	7.03	18953	100.62		3744
411	60–35–F	1.59	13.81	23880	.1638	12.07	.1390	10.24	26140	106.61		3747
412	60–40–F	1.50	12.45	22744	.2064	15.21	.1829	13.48	32592	101.20		3726

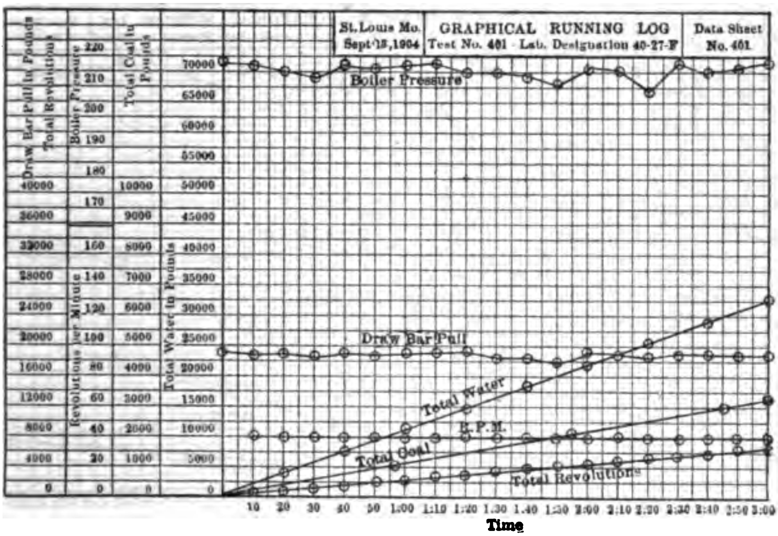
Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
401	40–27–F	85.45	5.27	525.3	10.93	663	394.0				9–13–04
402	40–35–F	86.91	5.33	556.0	8.38	879	514.5				9–14–04
403	40–40–F	87.95	5.51	435.9	6.57	1103	655.6				9–14–04
405	80–30–F	80.71	5.37	442.7	6.67	1009	645.5				9–10–04
407	80–40–F	88.60	6.29	261.8	3.94	1910	1091.6				9–12–04
408	80–55–F	90.48	4.51	206.1	3.11	2252	1386.2				9–17–04
410	60–30–F	80.83	5.09	549.7	8.29	813	519.8				9–15–04
411	60–35–F	84.88	5.38	395.1	5.95	1186	723.2				9–16–04
412	60–40–F	88.61	5.65	287.8	4.34	1560	992.8				9–16–04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 929.

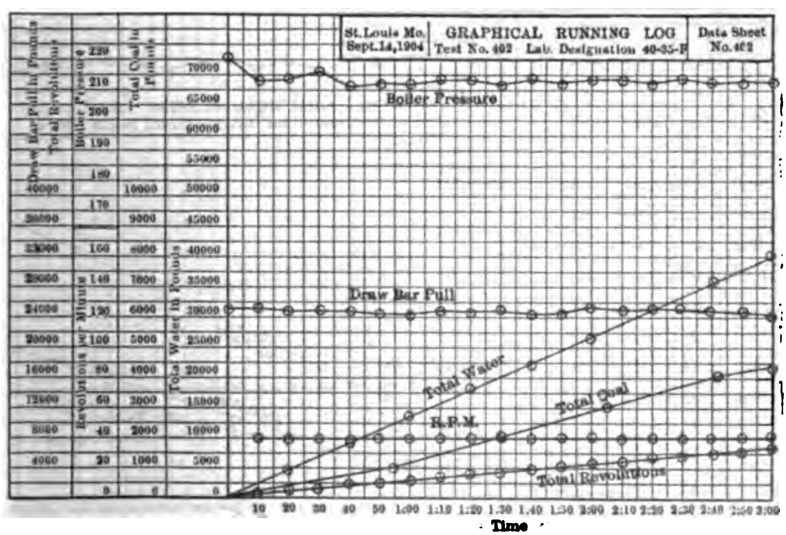
ATCHISON, TOPEKA AND SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft, Front of Diaphragm, Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	208	217	220	222	338	341
401	40-27-F	3	40.01	6.719	26.6	FULL	215.4	211.2	.51	1111	10766
402	40-35-F	3	40.00	6.718	33.9	"	213.5	208.8	.63	1465	13074
403	40-40-F	3	39.97	6.714	40.8	"	213.5	208.8	.91	1751	15204
405	80-30-F	3	80.00	13.435	28.8	"	214.2	210.2	1.06	1666	15334
407	80-40-F	3	80.00	13.435	41.4	"	213.0	208.0	2.29	2651	23232
408	80-55-F	3	81.28	13.652	51.4	"	213.5	206.3	3.68	4299	30603
410	60-30-F	3	60.00	10.077	26.1	"	214.1	209.7	.72	1437	13590
411	60-35-F	3	60.00	10.077	33.7	"	216.3	211.5	1.95	1935	16773
412	60-40-F	3	60.64	10.184	41.9	"	216.7	211.8	1.63	2381	19808

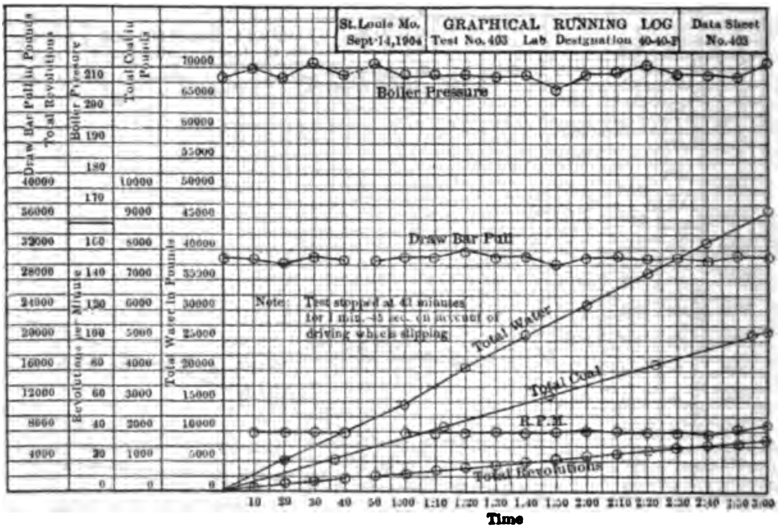
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		347	379	383	395	265	380	384	381	385	350	390
401	40-27-F	11.63	391.6	334.6	56.97	18680	2.73	3.20	26.47	30.97	74.31	5.27
402	40-35-F	10.72	510.8	443.9	66.91	24784	2.78	3.20	24.80	28.53	69.23	5.33
403	40-40-F	10.43	633.6	557.3	76.35	31131	2.69	3.06	23.38	26.58	66.82	5.51
405	80-30-F	11.05	631.4	509.6	121.77	14224	2.57	3.19	23.67	29.33	71.75	5.37
407	80-40-F	10.52	1088.8	964.7	124.11	26929	2.39	2.70	20.98	23.68	67.80	6.29
408	80-55-F	8.56	1257.9	1136.2	119.70	31240	3.37	3.74	24.04	26.60	54.69	4.51
410	60-30-F	11.38	511.3	410.7	100.62	15285	2.73	3.39	25.80	32.12	74.62	5.09
411	60-35-F	10.44	705.2	598.6	106.61	22279	2.68	3.16	23.22	27.36	67.24	5.38
412	60-40-F	10.00	888.8	787.6	101.20	29005	2.63	2.96	21.84	24.65	63.55	5.65



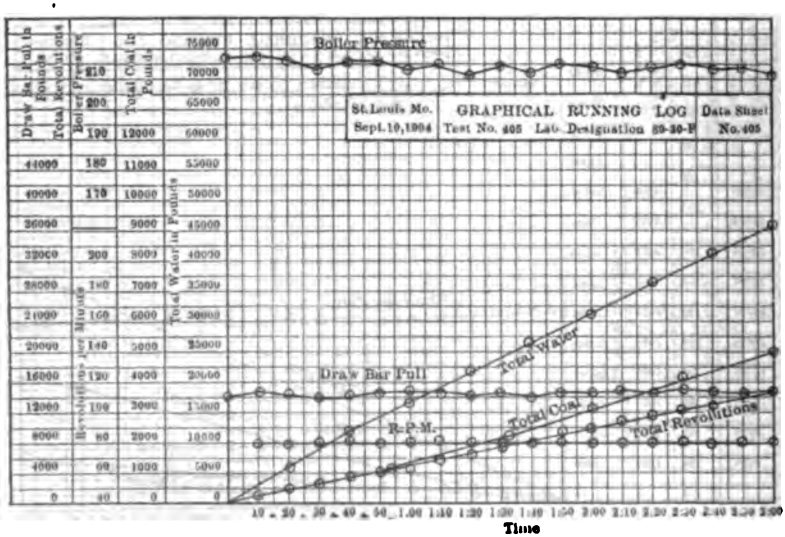
Test No. 401.



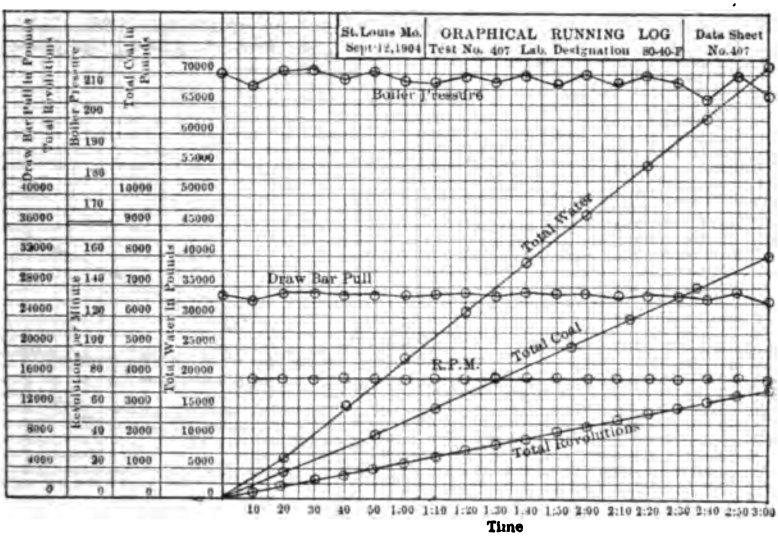
Test No. 402.



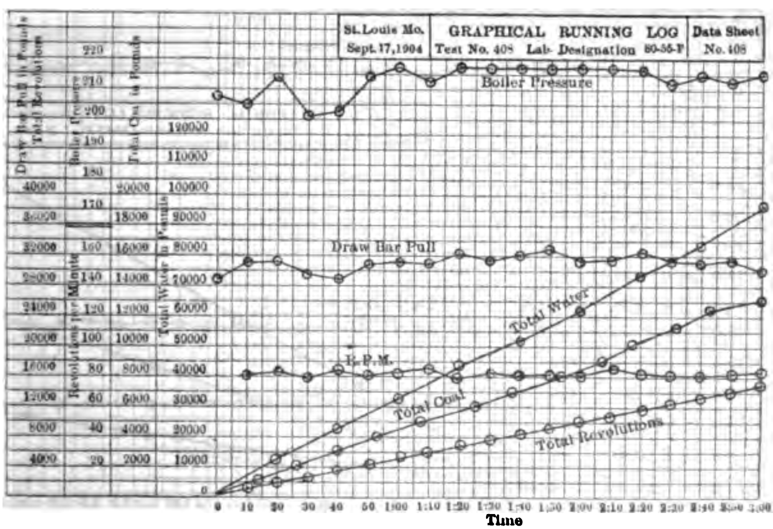
Test No. 403.



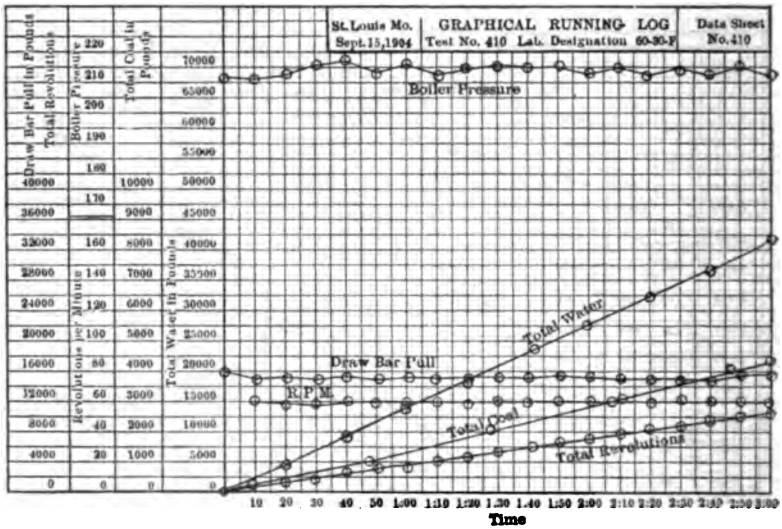
Test No. 405.



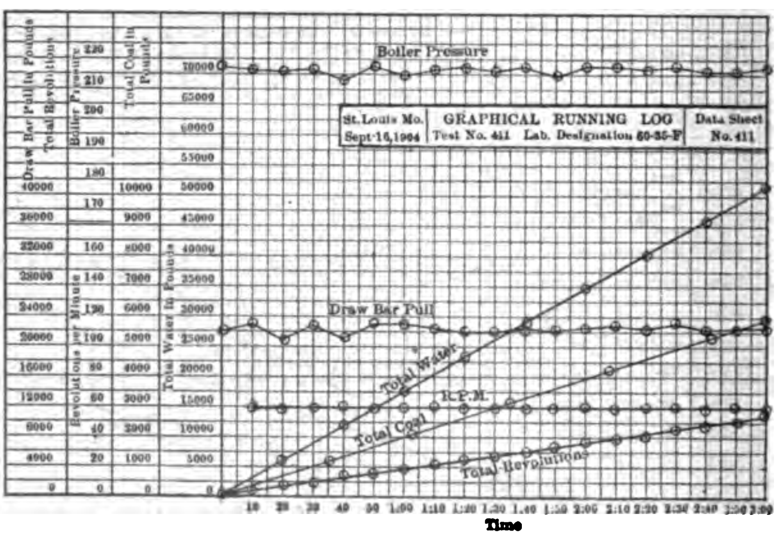
Test No. 407.



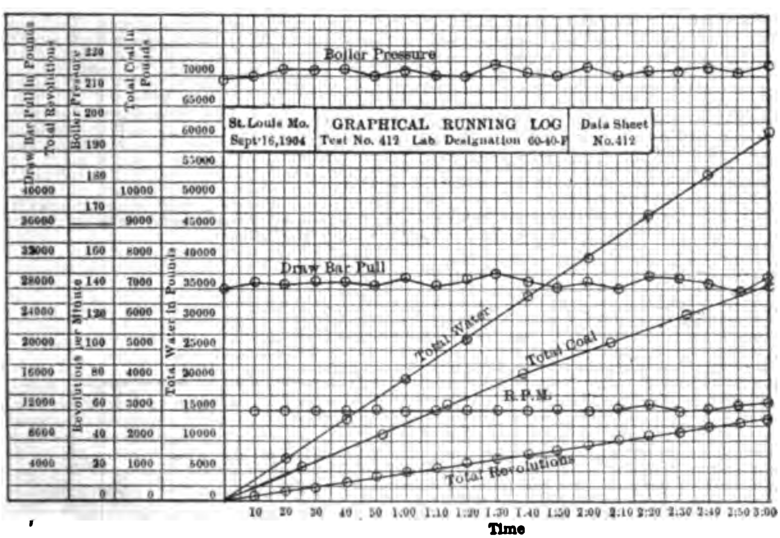
Test No. 408.



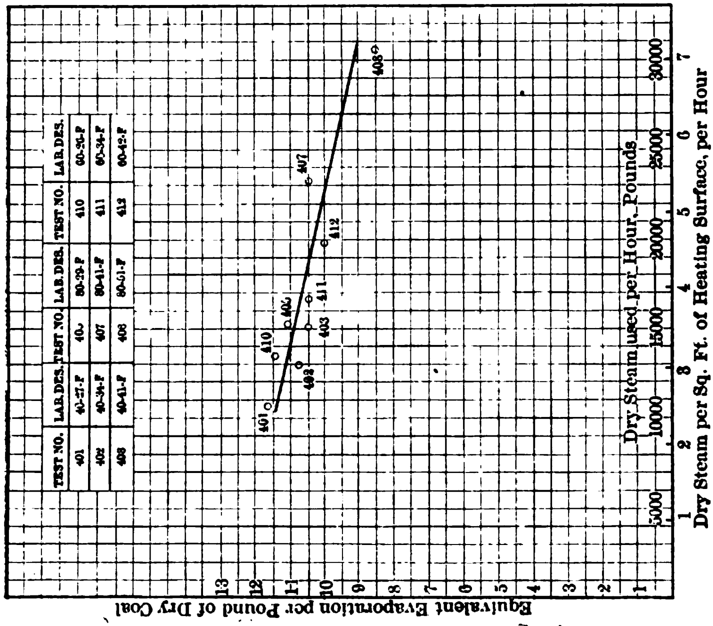
Test No. 410.



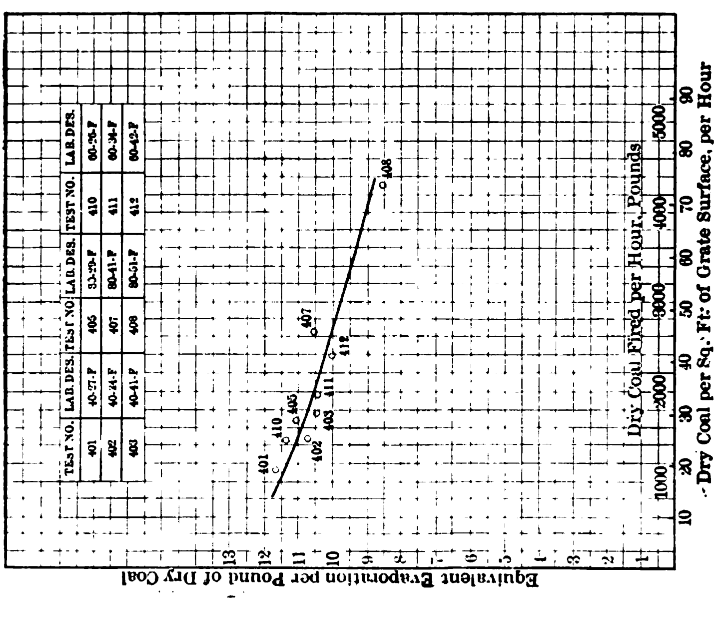
Test No. 411.


Boiler Pressure
St. Louis Mo. Sept 16, 1904
GRAPHICAL RUNNING LOG
Test No. 412 Lab Designation 60-40-F
Data Sheet No. 412
Draw Bar Pull
Total Water
Total Coal
R.P.M.
Total Revolutions
Draw Bar Pull in Pounds
Total Revolutions
Boiler Pressure
Total Coal in Pounds
Revolutions per Minute
Total Water in Pounds
Time

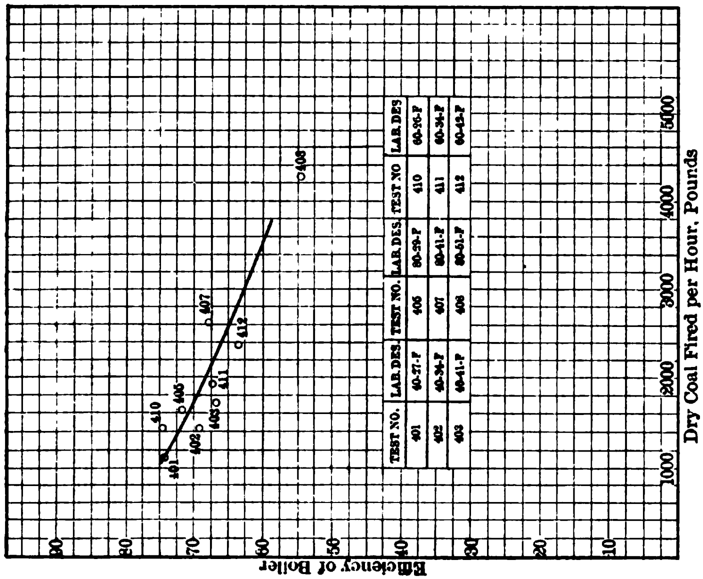
Test No. 412.



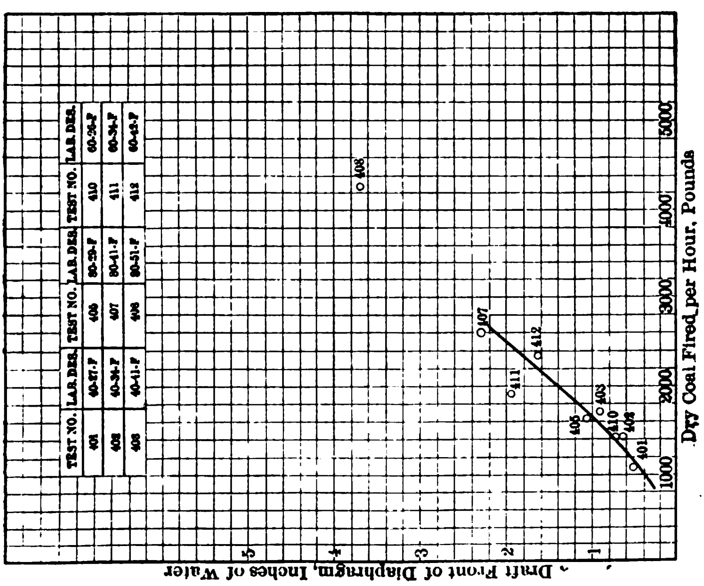
Plot No. 402.



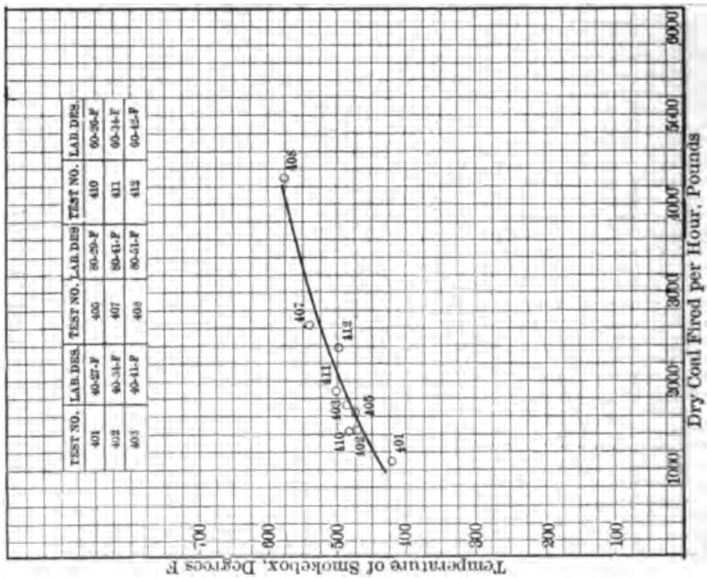
Test No. 401.



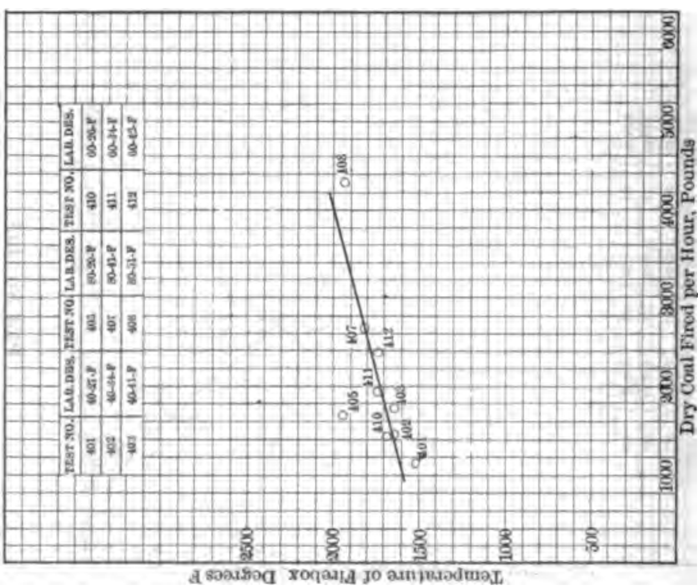
Test No. 404.



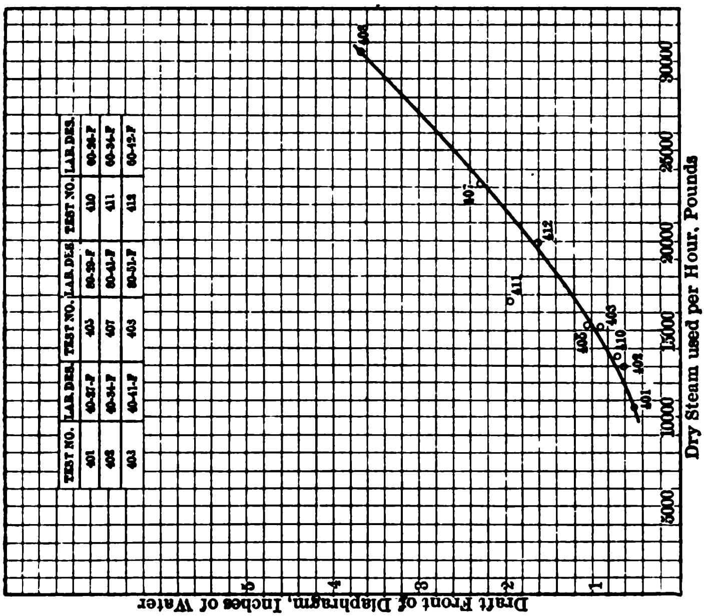
Plot No. 403.



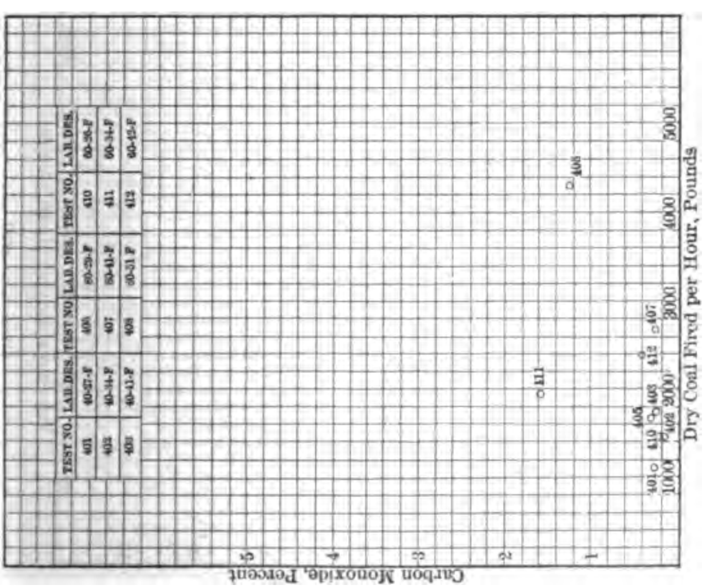
Plot No. 406.



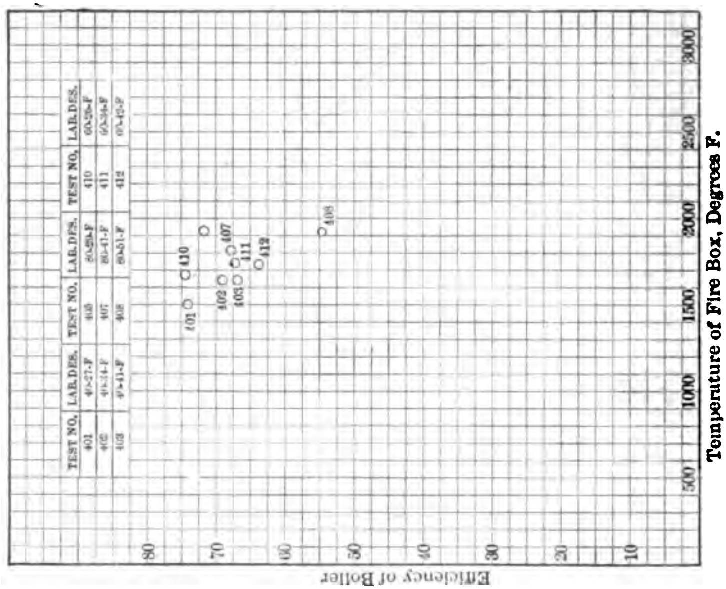
Plot No. 405.



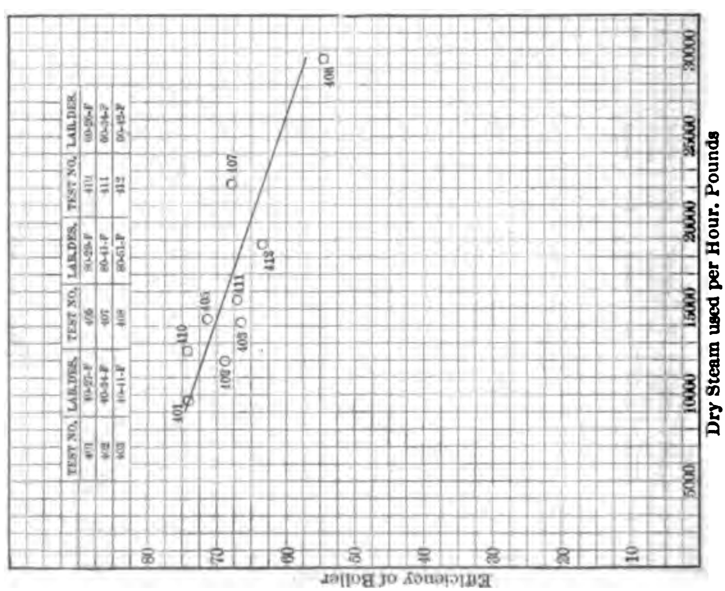
Plot No. 408.



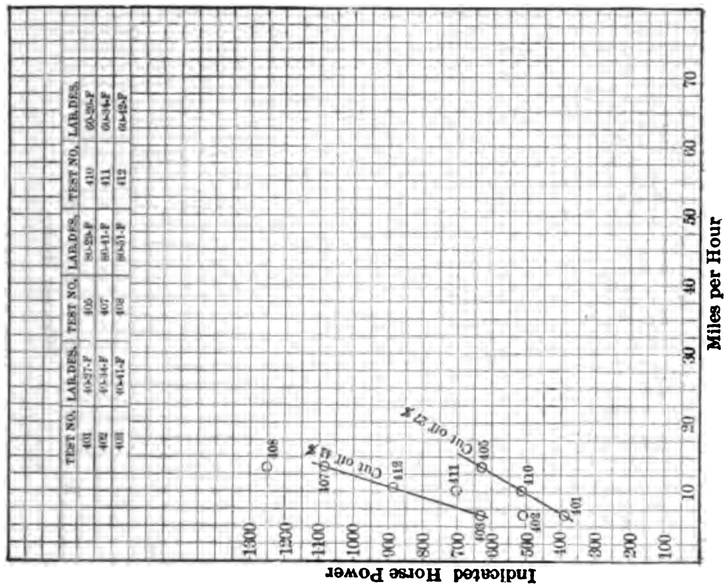
Plot No. 407.



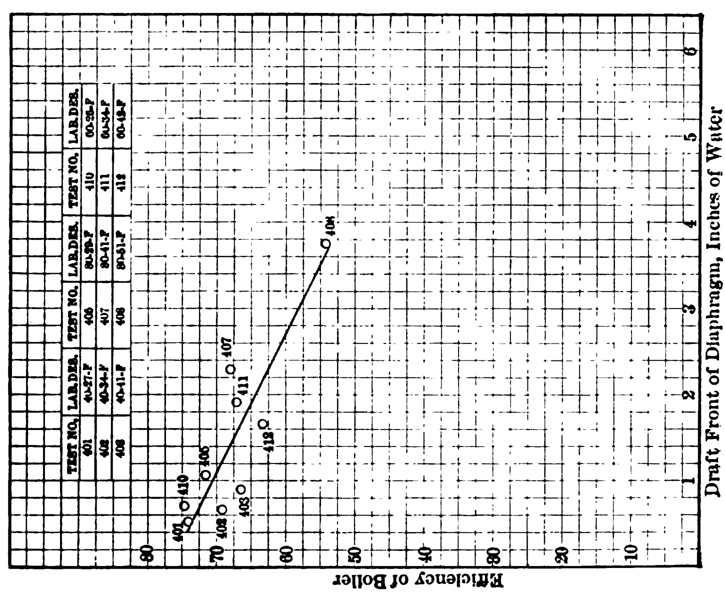
Plot No. 410.



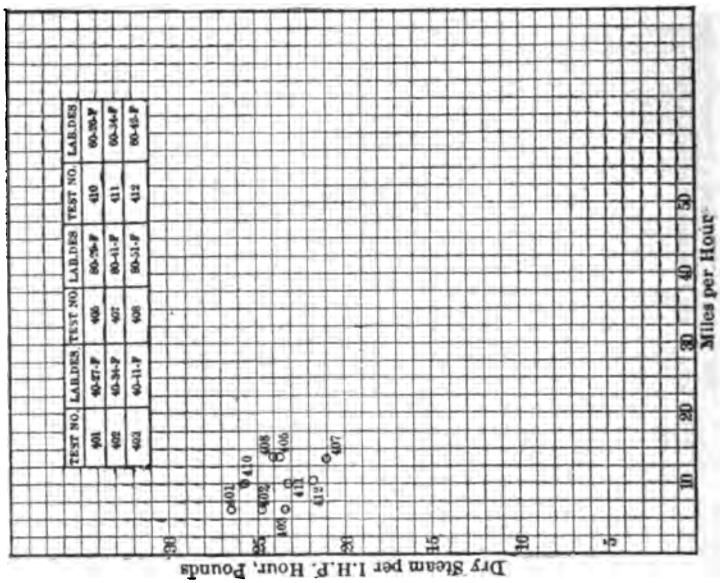
Plot No. 409.



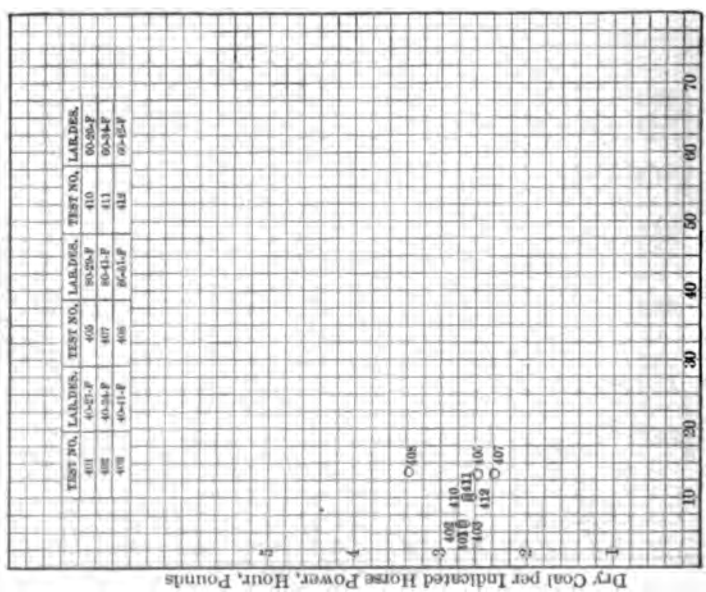
Plot No. 420.



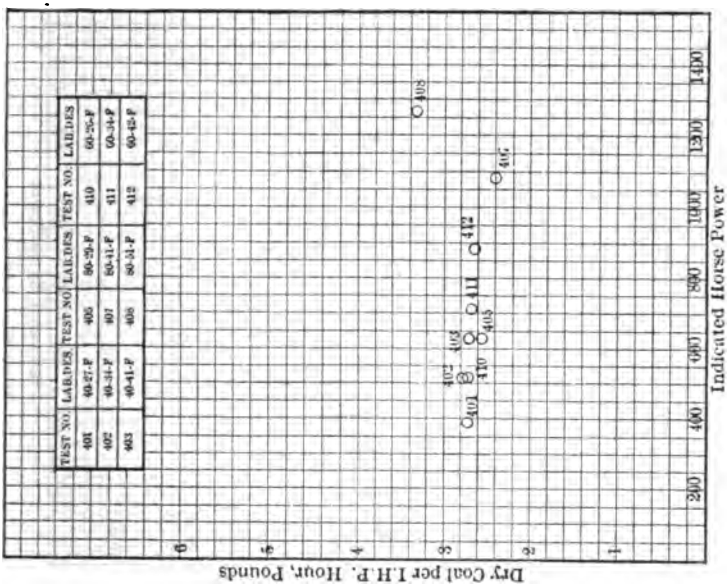
Plot No. 411.



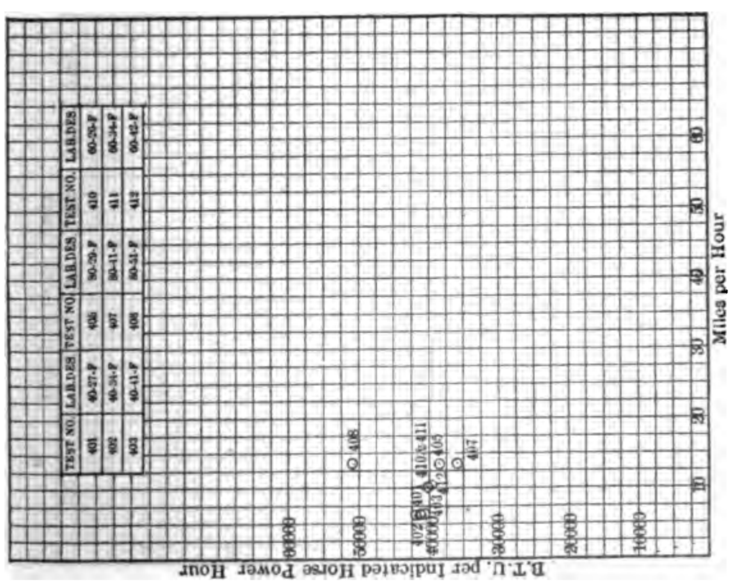
Plot No. 422.



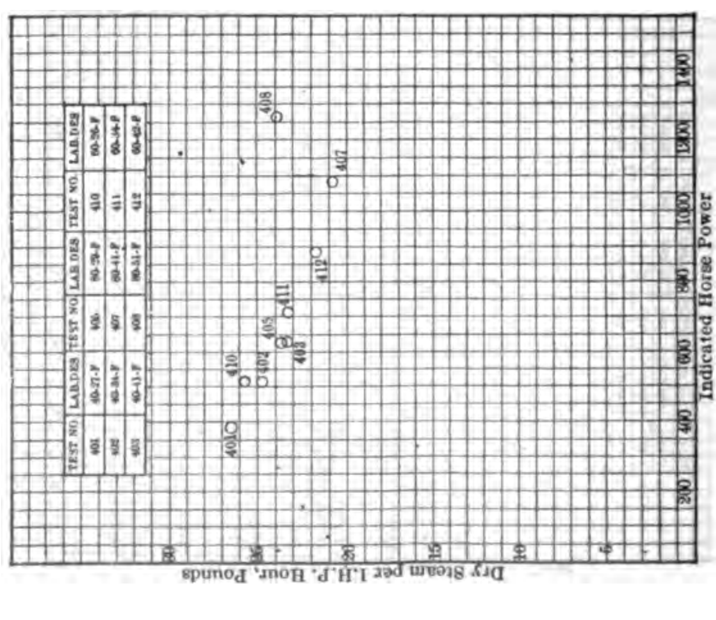
Plot No. 421.



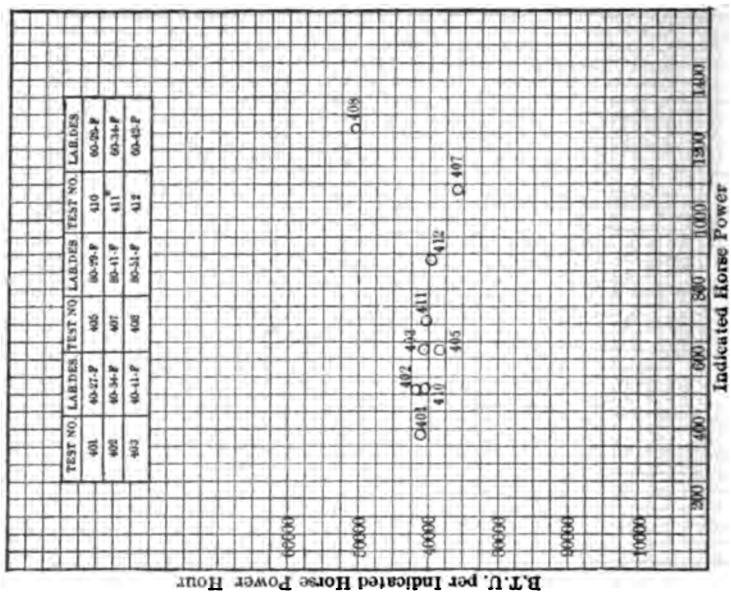
Plot No. 424.



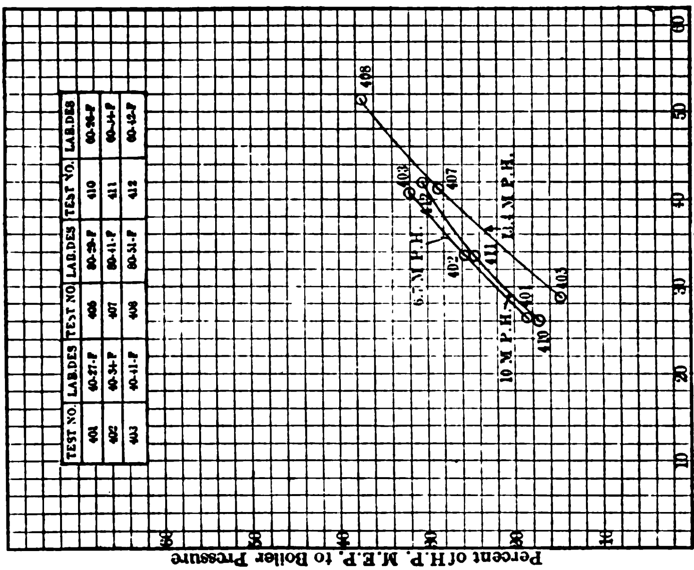
Plot No. 423.



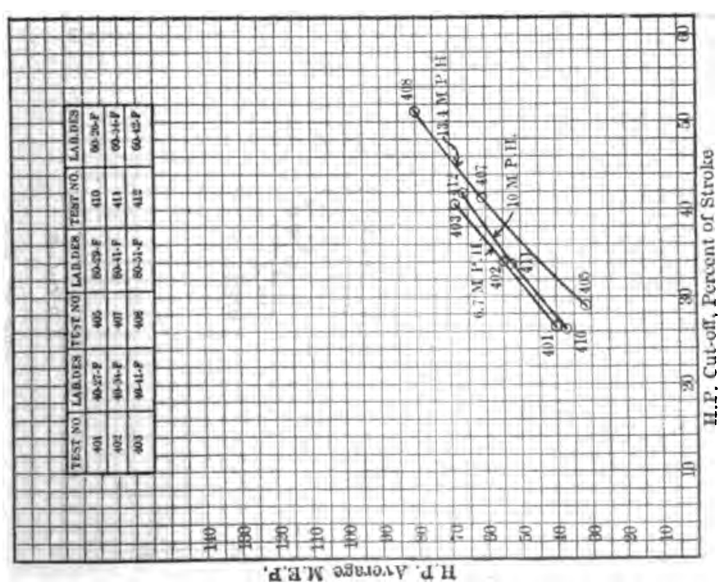
Plot No. 425



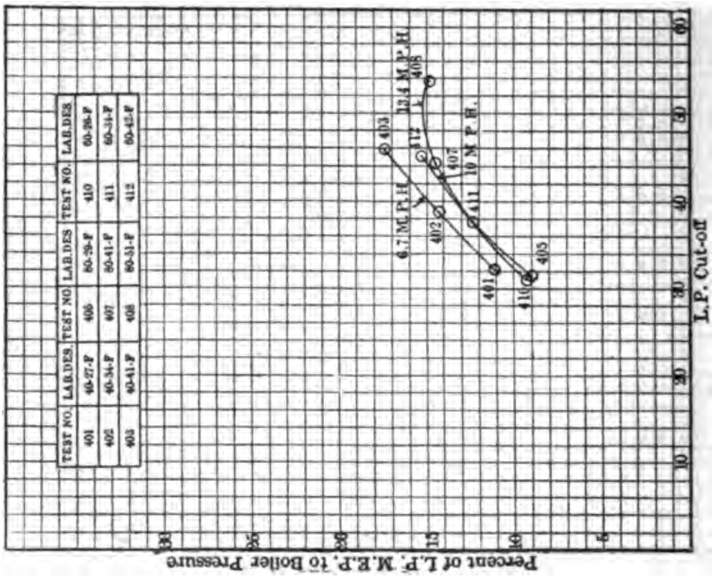
Plot No. 426.



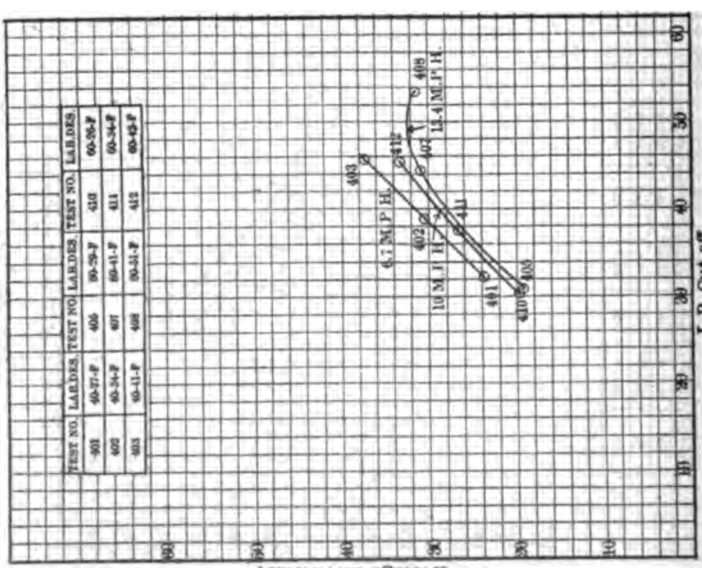
Plot No. 428.



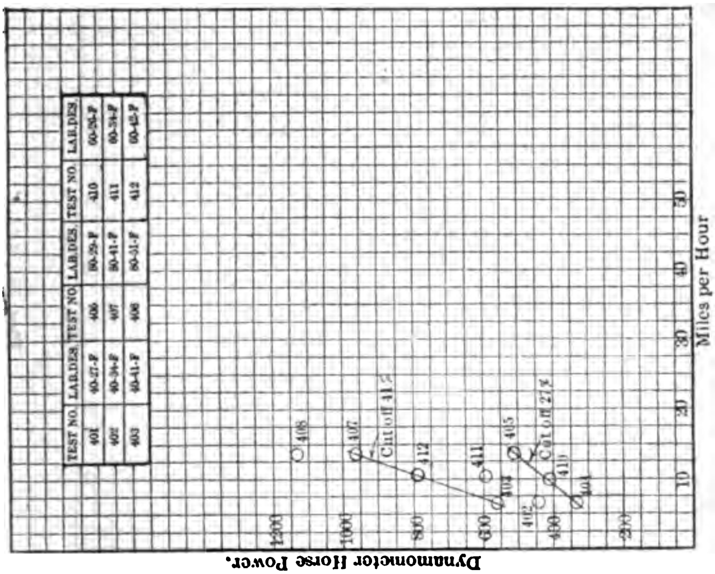
Plot No. 427.



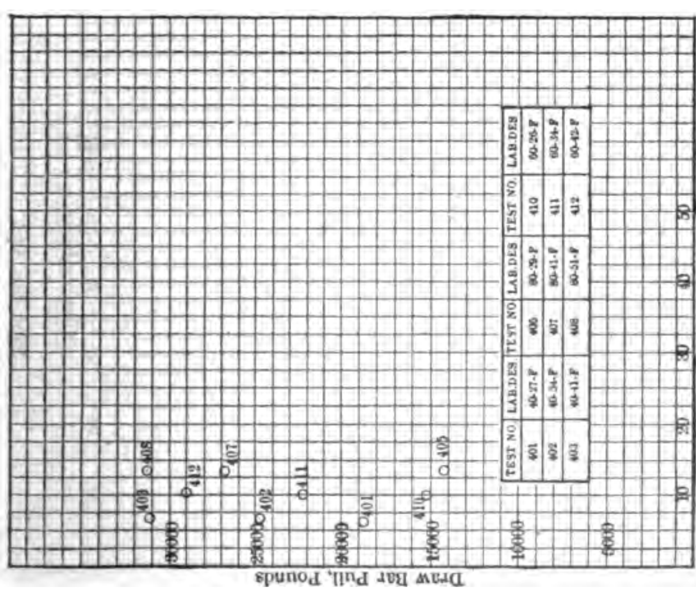
Plot No. 430.



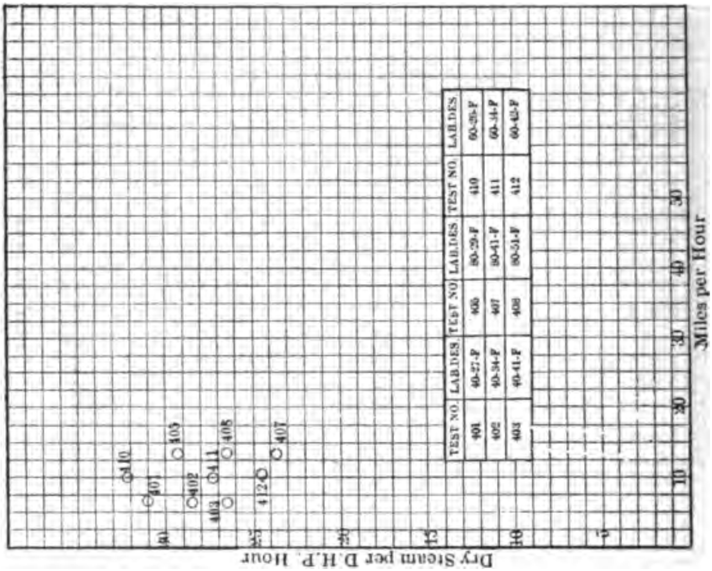
Plot No. 429.



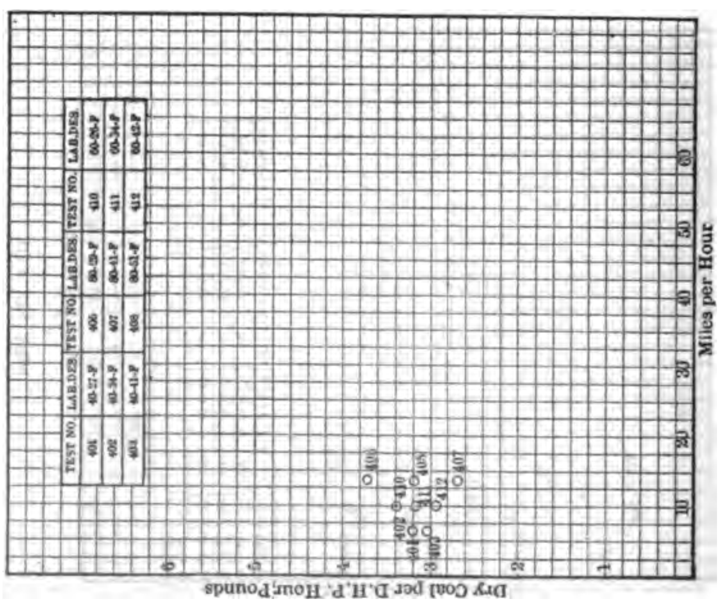
Plot No. 441.



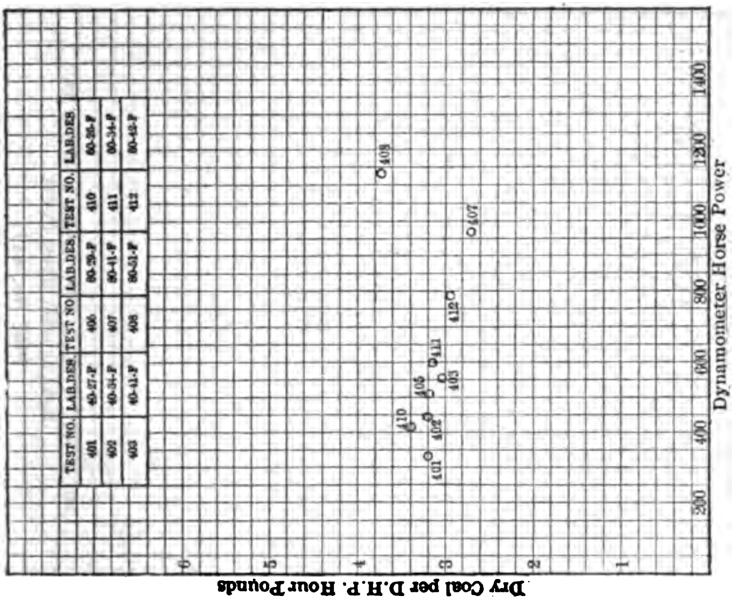
Plot No. 440.



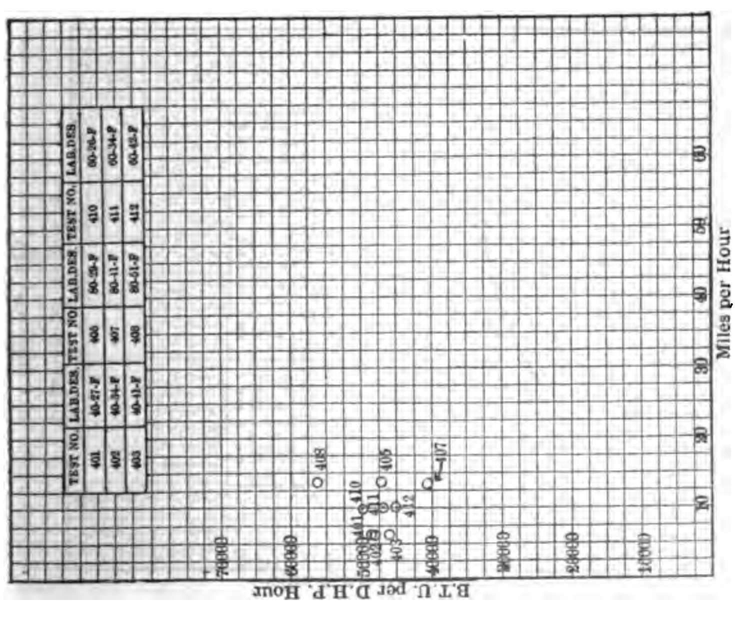
Plot No. 443.



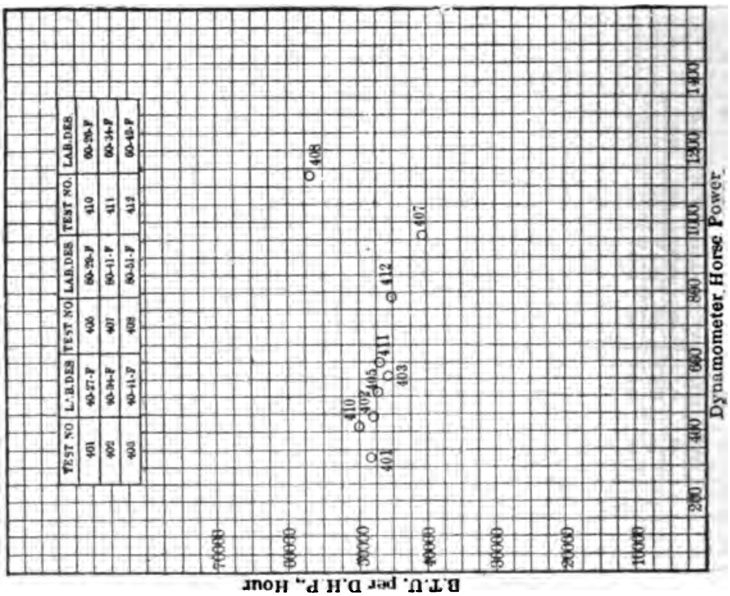
Plot No. 442.



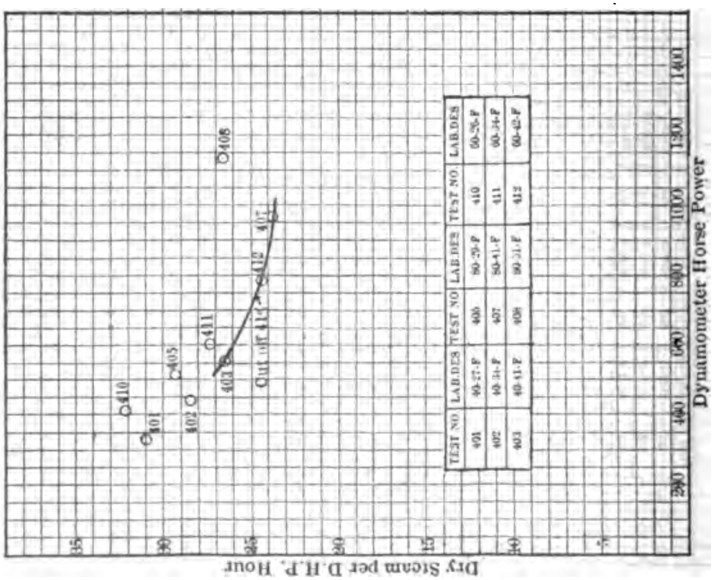
Plot No. 445.



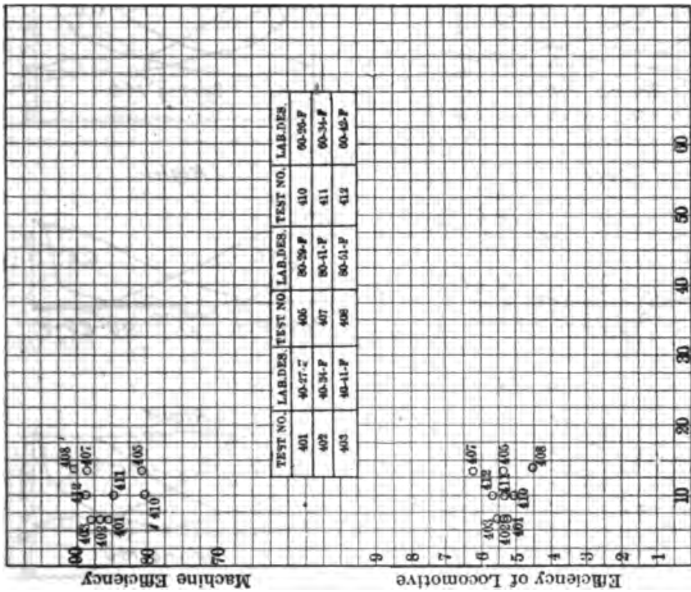
Plot No. 444.



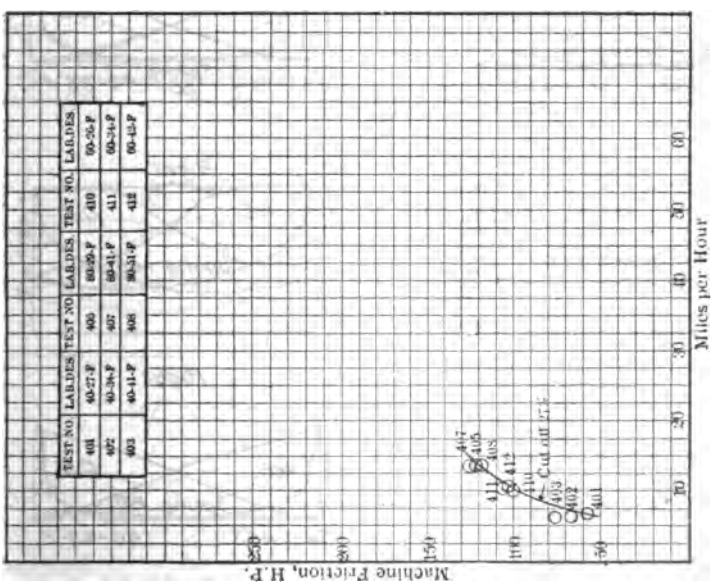
Plot No. 447.



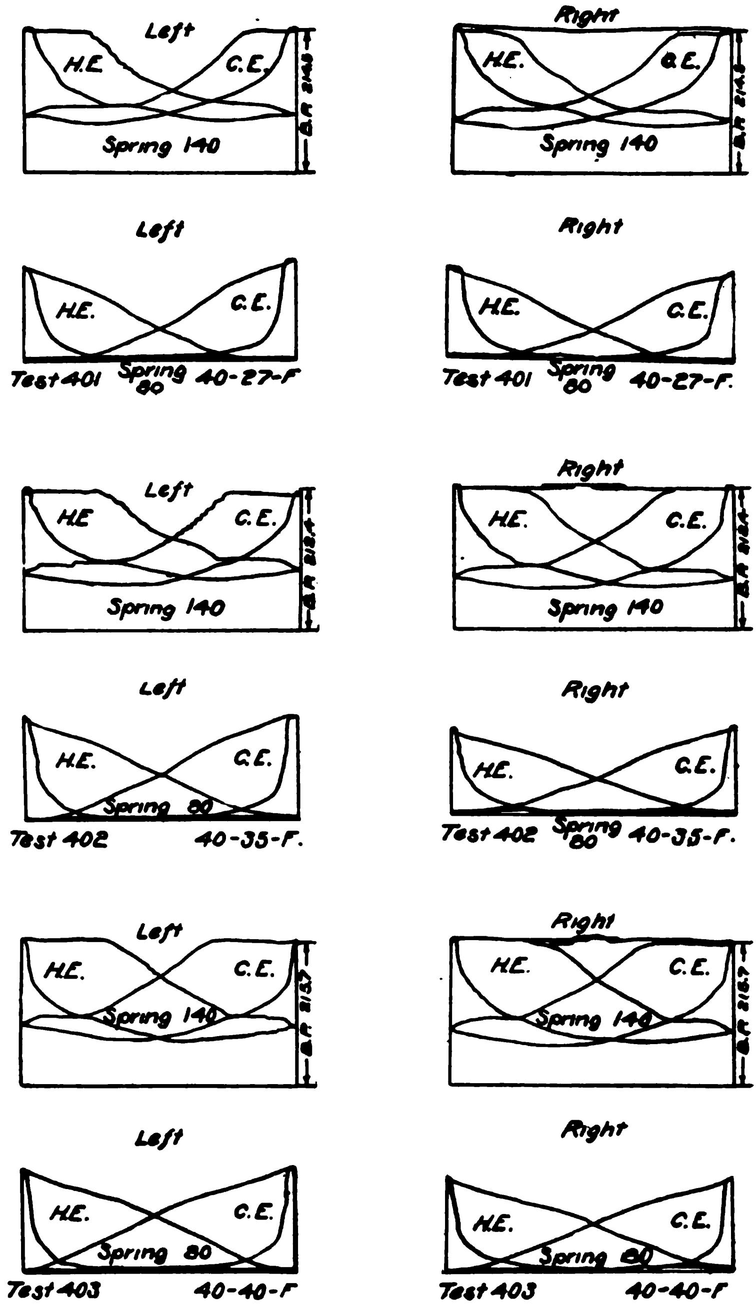
Plot No. 446.



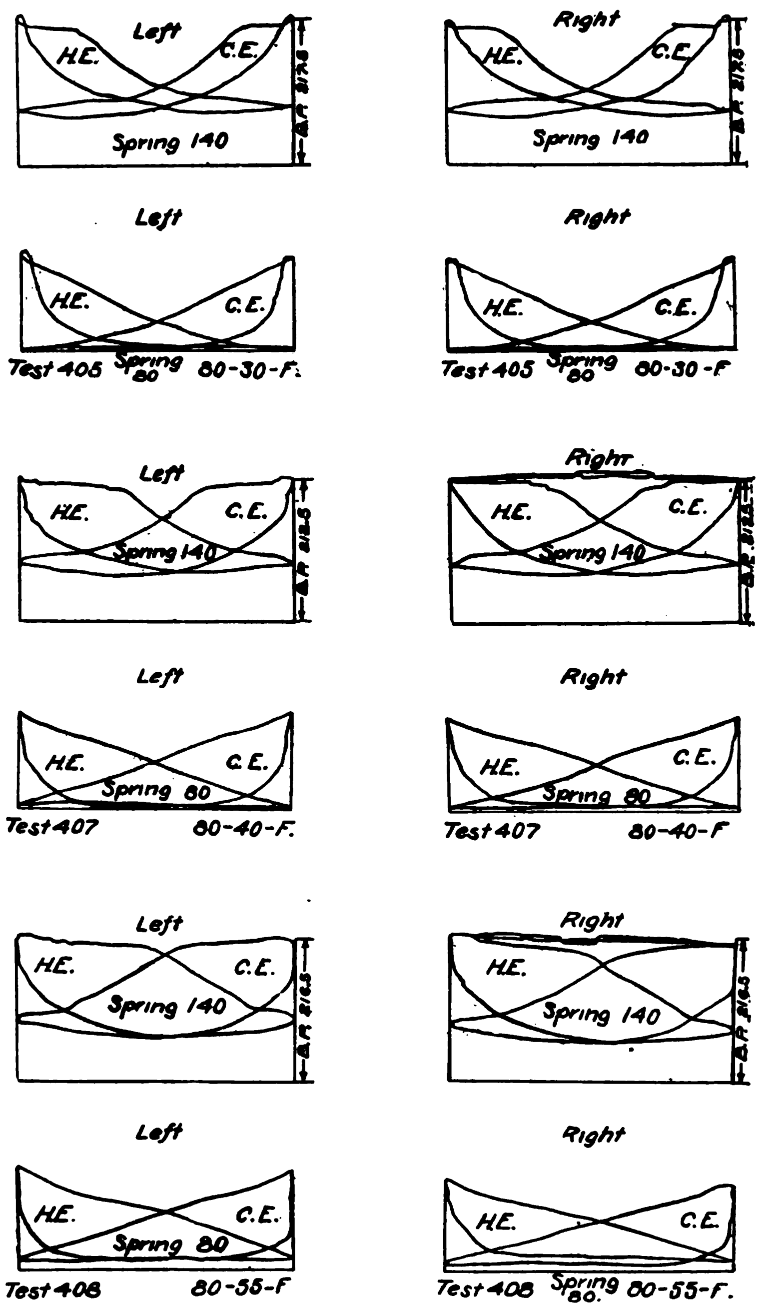
Plot No. 449.



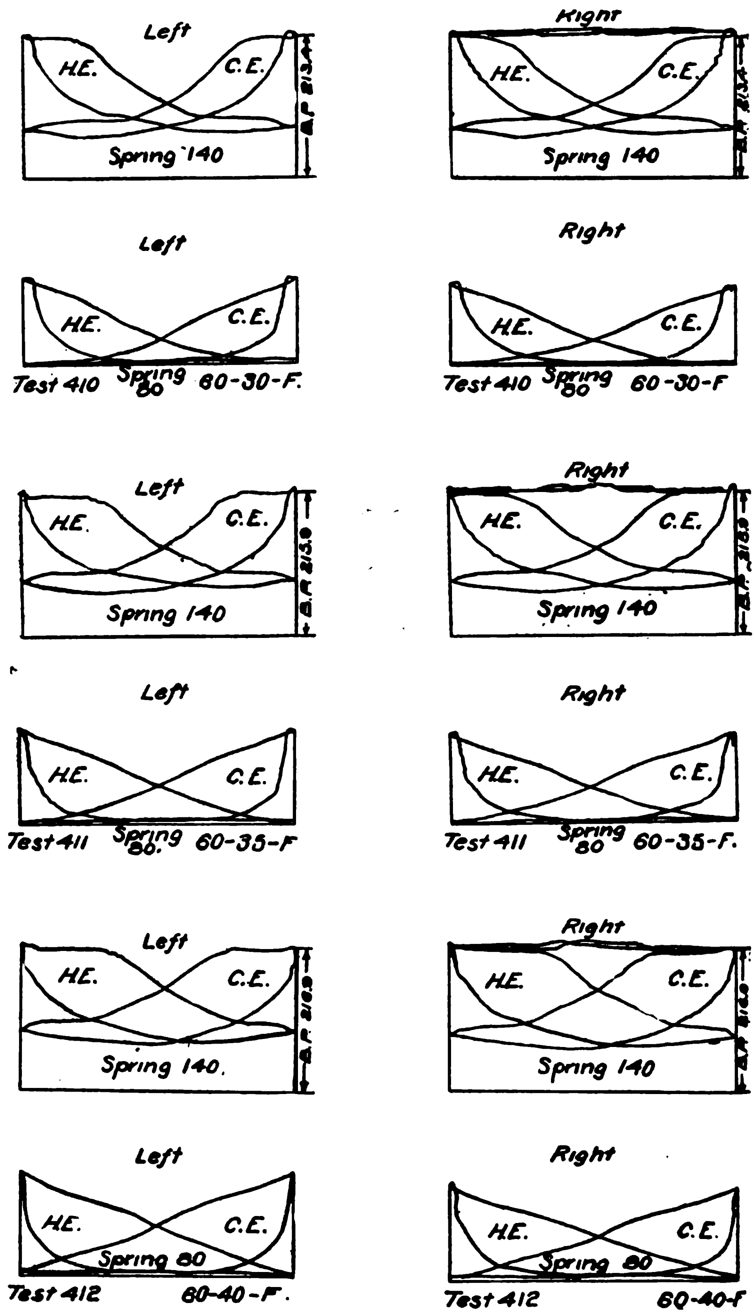
Plot No. 448.



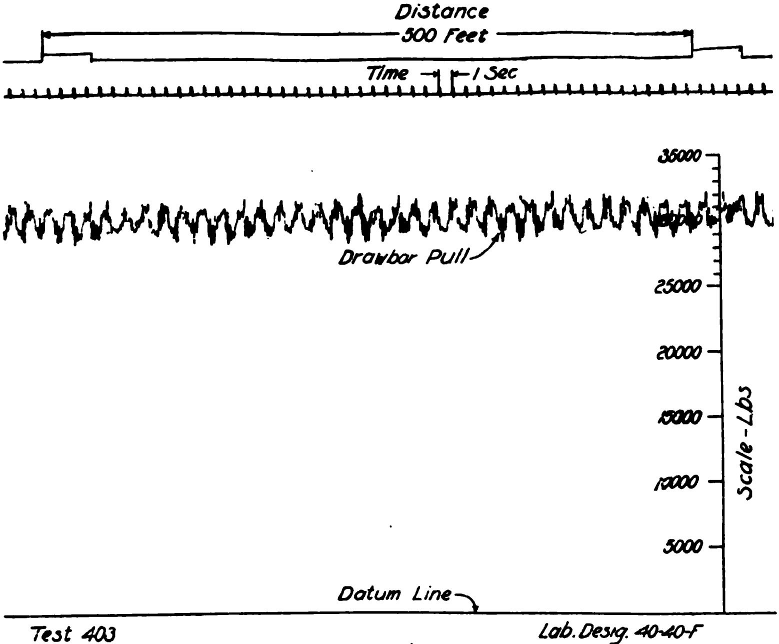
Typical Indicator Diagrams, Locomotive No. 929.



Typical Indicator Diagrams. Locomotive No. 929.

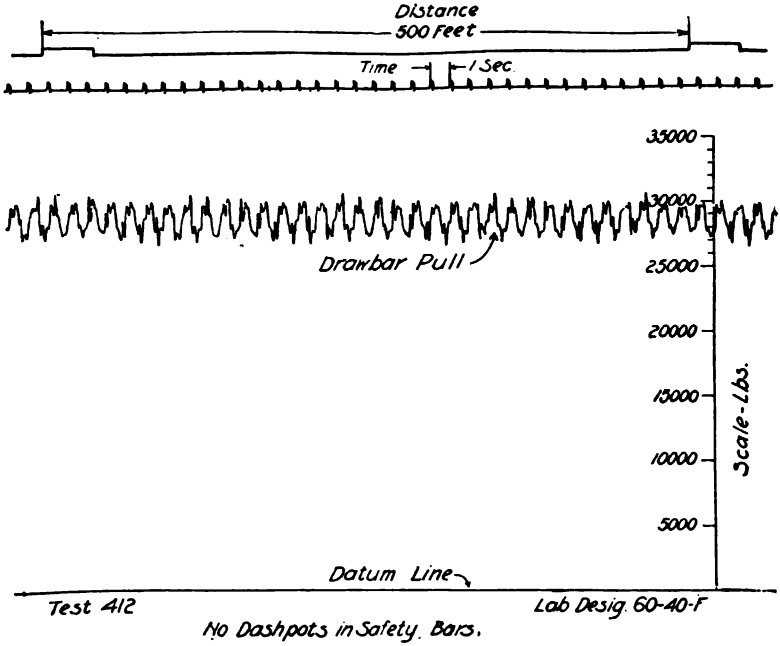


Typical Indicator Diagrams. Locomotive No. 929.



No Dashpots in Safety Bars

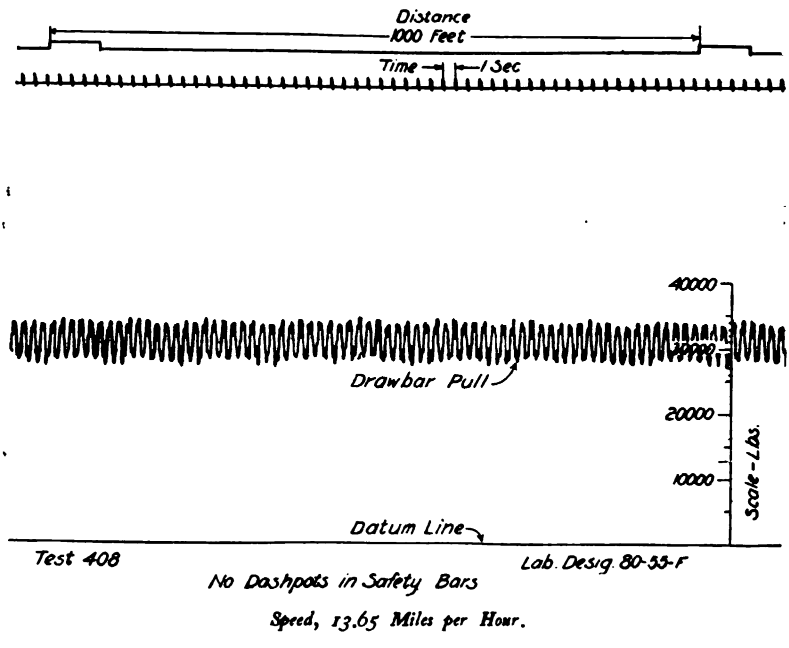
Speed, 6.71 Miles per Hour.



No Dashpots in Safety Bars.

Speed, 10.18 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 929.



Typical Dynamometer Diagram, Locomotive No. 929.

Fig. 412.

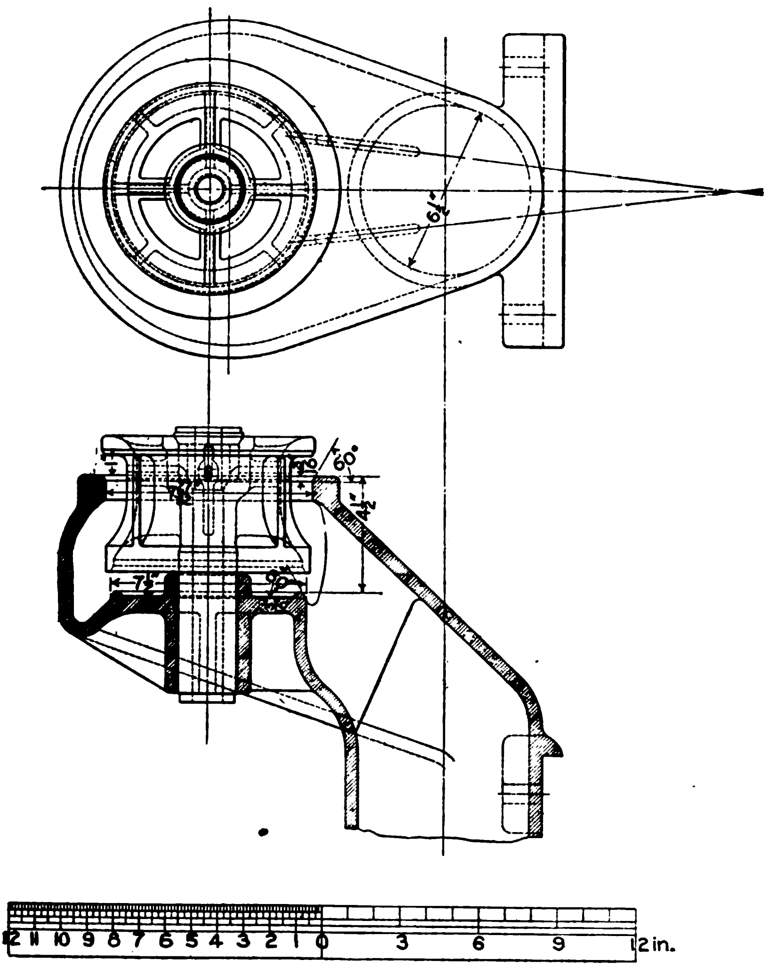


Fig. 418.— Throttle Valve, Locomotive No. 929.

CHAPTER XVII.

TESTS OF DE GLEHN ATLANTIC TYPE LOCOMOTIVE, PENNSYLVANIA RAILROAD COMPANY.

The fifth locomotive tested was No. 2512, owned by the Pennsylvania Railroad Company and built from the designs of Messrs. De Glehn and Du Bosquet, by the Societe Alsacienne de Constructions Mecaniques at Belfort, France. The locomotive was a four-cylinder balanced compound of the 4-4-2 type, and being the only locomotive of this type in this country, it has not been classified by the railroad company.

It was, with the exception of a few unimportant modifications, an exact duplicate of a number of locomotives furnished to the Northern Railway of France, by the same builders. It was the only one tested having Serve ribbed tubes in the boiler.

In the "DeGlehn" type the low pressure cylinders are between the frames, and the high pressure cylinders are outside the frames. The low pressure cylinders are side by side and drive inside cranks set quartering on the forward driving axle. The high pressure cylinders connect with outside crank pins in the drivers of the second driving axle.

The high pressure cylinders are placed back on the frames in relation to the low pressure cylinders, so that the main rods of the former are but 15½ inches longer than those of the latter.

This locomotive had a separate valve gear for both high pressure and low pressure cylinders, and the cut-off in the low pressure cylinders could be varied independently of the high pressure cut-off.

Both high pressure cylinders exhausted into a combined receiver and steam chest of 14.5 cubic feet capacity. A variable nozzle having an area of 17.5 to 43.5 square inches and operated from the cab, controlled the exhaust blast and was varied to suit the points of cut-off which were used.

When operated simple, the high pressure cylinders exhausted to the atmosphere and an auxiliary throttle admitted live steam to the low pressure cylinders.

The front flue sheet was made of steel about one inch thick and the back sheet was copper about 1 5-16 inches thick.

The fire-box was made of copper, both sides and crown sheet being a single piece 5-8 of an inch thick. The four top rows of staybolts were manganese bronze, the others copper and all were drilled.

This locomotive was placed on the testing plant twice, the first period being from September 15 to October 8, the second period being from November 25 to December 3, a total of thirty days, during which time ten tests were made. In the first period of twenty-one days six tests were obtained; the most serious delay being due to parts of the locomotive running hot when high speeds were attempted.

Seven and one-half days were lost on account of heating of rod brasses, chiefly at the back end of the low pressure main rod journals. The low pressure rods were on the inside cranks, where the brasses were necessarily narrow and, hence, the pressure per unit of area was high.

The critical speed of the De Glehn locomotive was found to be 197 revolutions.

On October 4 the dash-pots, which were designed to prevent the forward and backward motion of the locomotive, were installed, the adjustment being completed on October 5. The dash-pots stopped the motion due to the horizontal component of the unbalanced reciprocating parts, and it was then possible to run the locomotive above the critical speed.

The whole locomotive was unusually steady at all speeds, having very little motion of any kind.

On October 7, when the test at 320 revolutions was attempted, the left front driving box ran hot after seven minutes, and it was necessary to stop. The construction of this locomotive was such that it was impossible to examine and repack the driving box cellars without dropping the driving wheels. Not having any drop pit, this was impossible at the testing plant.

The locomotive was sent to the Terre Haute shops of the Vandalia Line, repaired and run on the road until it was thought to be in good condition, and was then returned to St. Louis.

After the tests on the Atchison, Hanover and New York Central locomotives were completed, the De Glehn was again placed on the testing plant, on November 25 and was taken off on December 3. In this period of nine days, four tests were obtained. Considerable difficulty was encountered in getting the locomotive to steam, it having been impossible to run at cut-offs as long as those obtained on the road.

The coal used was soft, and readily broke into small pieces. There was no shaking arrangement in the grates and if the nozzle was decreased in size to increase the draft and clear the fire, there was a tendency to fill up the smoke-box with cinders. For these reasons, the indicated horse powers obtained were not as large as the maximum reported from road tests.

This locomotive will be very carefully tested on the testing plant as soon as it is erected at Altoona, with a view to developing the value of this system of compounding.

After November 29 no more tests were obtained, due to heating of the back ends of the main rods, and the locomotive was removed from the plant on December 3. In these twenty-six working days two and one half days were lost on account of difficulties experienced with the plant and seventeen due to troubles with the locomotive.

The principal dimensions and the details of the locomotive are given in Appendix 500. The principal nominal dimensions are shown in the following table:

Total weight, pounds	164,000
Weight on drivers, pounds	87,850
Cylinders (compound), inches	14 3-16 & 23 11-16 x 25¼
Diameter of drivers, inches	80
Fire-box heating surface, square feet	177.28
Heating surface in tubes (water side) sq. ft	1468.87
Total heating surface (based on water side of tubes) square feet	1646.15

*Total heating surface (based on fire side of tubes) square feet..........	2656.48
Grate area, square feet..................	33.39
Boiler pressure, pounds per square inch..	225
Valves "D" Slide, H. P. balanced; L. P., not balanced.	
Valve motion........................	Walschaert.
Fire-box, type........................	Belpaire.
Number of tubes (Serve).............	139
Outside diameter of tubes, inches.......	2¾
Length of tubes, inches................	176.14

The maximum tractive effort was 22,698 pounds working simple and 16,700 pounds working compound, which was calculated on the assumption that 80 per cent. of the boiler pressure (225 pounds) was available as mean effective pressure at starting. On this basis the ratio of weight on drivers to maximum tractive effort was 3.87:1 working simple and 5.26:1 working compound.

TESTS.

The tests which have been run, together with the laboratory designation and dates of running, are as follows:

Test No.	Laboratory Designation	Date
501	80–$\frac{25}{45}$–F	September 23rd.
502	80–$\frac{35}{60}$–F	" 24th.
505	160–$\frac{25}{45}$–F	" 26th.
506	160–$\frac{25}{45}$–F	" 27th.
507	160–$\frac{40}{60}$–F	November 26th.
508	160–$\frac{50}{70}$–F	October 3rd.
510	240–$\frac{25}{45}$–F	" 7th.
511	240–$\frac{30}{55}$–F	November 29th.
512	240–$\frac{35}{60}$–F	" "
513	280–$\frac{30}{55}$–F	" "

The numerator of the second term in the above laboratory designation represents the nominal cut-off in the high pressure cylinders, and the denominator represents the nominal cut-off in the low pressure cylinders.

* Used in Calculations.

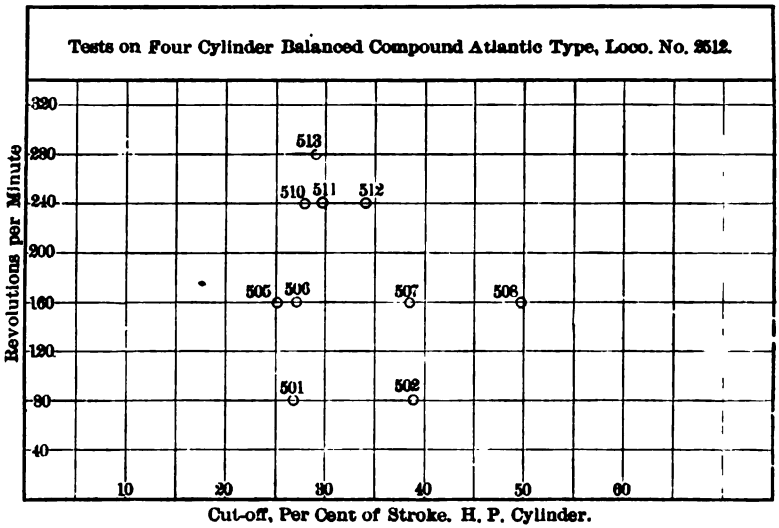


Fig. 501.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 501.

No test was shorter than 74.4 minutes, while the longest was 180 minutes.

The lowest average boiler pressure was 206.4 pounds, while the highest was 219.7 pounds. The feed water temperature ranged from 74.7 degress to 47.0 degrees, on account of the interval between the first and last series of tests. The total coal fired per square foot of grate area follows:

In 3 tests ....between 50 and 100 lbs.
In 4 tests ....between 100 and 150 lbs.
In 1 test ....between 150 and 200 lbs.
In 2 tests ....between 200 and 300 lbs.

EVAPORATION—TABLE 502.

The evaporation per hour was between the limits of 7,066 pounds and 20,184 pounds.

The quality of the steam in the dome was high in all of the tests.

The quality of the steam in the branch pipe was slightly higher than in the dome. In this locomotive the steam does not pass through the smoke-box on its way to the cylinders, but is

TABLE No. 501—GENERAL BOILER CONDITIONS.

Identification of Tests: Test Number	Identification of Tests: Laboratory Designation	Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch: Boiler Pressure	Average Pressure Lbs. Per Sq. Inch: Atmospheric Pressure	Average Temperature, Degrees Fahr.: Of Laboratory	Average Temperature, Degrees Fahr.: Of Feed Water	Total Coal Fired Per Sq. Ft. of Grate Lbs.
		Cal.	217	221	208	211	Cal.
501	80–$\frac{25}{45}$ F	180	212.0	14.531	78.1	69.4	62.59
502	80–$\frac{35}{60}$–F	109.5	215.2	14.498	76.7	71.7	55.38
505	160–$\frac{25}{45}$–F	99.96	219.7	14.378	83.4	72.5	58.40
506	160–$\frac{25}{45}$–F	180	219.6	14.458	84.0	74.7	114.10
510	240–$\frac{25}{45}$–F	120	212.5	14.595	56.0	68.8	106.64
511	240–$\frac{30}{55}$–F	120	218.9	14.445	48.4	47.0	144.92
507	160–$\frac{40}{60}$–F	180	214.6	14.691	36.8	47.4	203.86
512	240–$\frac{35}{60}$–F	120	217.5	14.417	52.0	47.2	159.65
513	280–$\frac{30}{55}$–F	74.40	215.0	14.429	52.4	47.0	108.65
508	160–$\frac{50}{70}$–F	180	206.4	14.483	72.9	71.9	275.58

TABLE No. 502—EVAPORATION.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Water and Steam: Total Lbs. Evaporated	Water and Steam: Lbs. Evaporated Per Hour	Calorimeter Results: Quality of steam in Dome	Calorimeter Results: Quality of steam in Branch Pipe	Calorimeter Results: Degrees Superheat in Branch Pipe	Equivalent Evaporation Lbs. Per Hour
		Cal.	264	340	*228	229	230	344
501	80–$\frac{25}{45}$–F	180	21198	7066	.9851	.9863	0	8416
502	80–$\frac{35}{60}$–F	109.5	17779	9742	.9845	.9865	0	11580
505	160–$\frac{25}{45}$–F	99.96	18347	11007	.9849	.9863	0	13089
506	160–$\frac{25}{45}$–F	180	34940	11646	.9843	.9863	0	13810
510	240–$\frac{25}{45}$–F	120	27323	13662	.9842	.9841	0	16273
511	240–$\frac{30}{55}$–F	120	31273	15636	.9813	.9881	0	18933
507	160–$\frac{40}{60}$–F	180	49798	16599	.9815	.9880	0	20091
512	240–$\frac{35}{60}$–F	120	36482	18241	.9815	.9883	0	22088
513	280–$\frac{30}{55}$–F	74.40	24023	19373	.9812	.9885	0	23453
508	160–$\frac{50}{70}$–F	180	60552	20184	.9859	.9874	0	23999

conveyed to the high pressure cylinders from the dome by an outside pipe.

BOILER POWER—TABLE 503.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 252 to 718.7.

The equivalent evaporation per square foot of heating surface ranged from 3.17 to 9.04 pounds per hour.

TABLE No. 503—BOILER POWER.

Identification of Test		Duration of Test. Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft of Grate Surface
		Cal,	Cal.	845	849	Cal.	Cal.
501	80-$\frac{25}{45}$-F	180	252.0	3.17	244.0	.092	7.31
502	80-$\frac{35}{60}$-F	109.5	346.8	4.36	335.7	.126	10.05
505	160-$\frac{25}{45}$-F	99.96	392.0	4.93	379.4	.143	11.36
506	160-$\frac{25}{45}$-F	180	413.6	5.20	400.3	.151	11.99
510	240-$\frac{25}{45}$-F	120	487.4	6.13	471.7	.178	14.13
511	240-$\frac{30}{55}$-F	120	567.1	7.13	548.8	.207	16.44
507	160-$\frac{40}{60}$-F	180	601.7	7.56	582.4	.219	17.44
512	240-$\frac{35}{60}$-F	120	661.5	8.32	640.3	.241	19.17
513	280-$\frac{30}{55}$-F	74.40	702.4	8.83	679.8	.256	20.36
508	160-$\frac{30}{70}$-F	180	718.7	9.04	695.6	.262	20.83

The maximum boiler horse power developed was 695.6, the horse power being calculated on the usual basis.

The horse power developed per square foot of heating surface ranged from .092 to .262.

The maximum horse power developed per square foot of grate surface is equivalent to about one horse power for each .048 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 504.

The total coal fired ranged from 1,834 pounds to 9,116 pounds, and the amount per hour from 690 pounds to 3,038 pounds.

The dry coal fired per square foot of grate area per hour ranged from 20.67 pounds to 91.0 pounds.

The coal burned per square foot of heating surface per hour ranged from .260 to 1.144 pounds.

TABLE No. 504—COAL AND RATE OF COMBUSTION.

Identification of Test				Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation	Duration of Test, Minutes	Total Dry Coal Fired	Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq. Ft. of Grate Per Hour	Dry Coal Per Sq. Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
501	80-$\frac{25}{45}$-F	180	2071	1937	690	646	20.67	.260
502	80-$\frac{35}{60}$-F	109.5	1834	1705	1005	934	30.09	.378
505	160-$\frac{25}{45}$-F	99.96	1929	1806	1157	1084	34.66	.436
506	160-$\frac{25}{45}$-F	180	3778	3578	1259	1193	37.71	.474
510	240-$\frac{25}{45}$-F	120	3522	3280	1761	1640	52.74	.663
511	240-$\frac{30}{55}$-F	120	4791	4462	2395	2231	71.74	.902
507	160-$\frac{40}{60}$-F	180	6742	6401	2247	2134	67.31	.846
512	240-$\frac{35}{60}$-F	120	5282	4810	2641	2405	79.09	.994
513	280-$\frac{30}{55}$-F	74.40	3593	3389	2897	2733	86.77	1.091
508	160-$\frac{50}{70}$-F	180	9116	8634	3038	2878	91.00	1.144

TABLE No. 505—CINDERS AND SPARKS.

Identification of Test			Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation	Duration of Test, Minutes	Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
501	80-$\frac{25}{45}$-F	180	42.3	5.7	48.0	——	——
502	80-$\frac{35}{60}$-F	109.5	67.9	9.9	77.8	——	——
505	160-$\frac{25}{45}$-F	99.96	89.4	19.2	108.6	——	——
506	160-$\frac{25}{45}$-F	180	67.0	8.0	75.0	11224	10344
510	240-$\frac{25}{45}$-F	120	1205.5	21.0	1226.5	10666	8959
511	240-$\frac{30}{55}$-F	120	127.5	17.0	144.5	13012	12799
507	160-$\frac{40}{60}$-F	180	154.0	20.0	174.0	12799	12372
512	240-$\frac{35}{60}$-F	120	219.0	31.0	250.0	13225	12799
513	280-$\frac{30}{55}$-F	74.40	246.7	33.1	279.8	13225	12372
508	160-$\frac{50}{70}$-F	180	711.7	115.0	826.7	12585	11519

CINDERS AND SPARKS—TABLE 505.

The maximum calorific value of the cinders was 13,225 B. T. U., and the maximum calorific value of the sparks was 12,799 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 506.

Relations derived from Figs. 502 to 504 inclusive are given below. The methods employed in obtaining these equations are explained in detail in Chapter XIII.

$$D = .0382\ G \qquad (501)$$
$$T_f = 3.05\ G + 1640 \qquad (502)$$
$$T_s = 1.66\ G + 450 \qquad (503)$$
$$T_f - T_s = 1.39\ G + 1190 \qquad (504)$$
$$H = .079\ G + 1.9 \qquad (505)$$
$$G = .719\,(T_f - T_s) - 856 \qquad (506)$$
$$G = 12.66\ H - 24 \qquad (507)$$
$$H = .057\ (T_f - T_s) - 65.73 \qquad (508)$$

The fire-box temperatures ranged from 1,588 to 2,044 degrees Fahrenheit, and the smoke-box temperatures from 483 to 594 degrees Fahrenheit. As the rate of combustion increased

TABLE No. 506—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water			Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In Smoke-Box	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	224	225	212	207	339
501	80-$\frac{25}{45}$-F	180	.38	.21	.04	1588	483	20.67
502	80-$\frac{35}{60}$-F	109.5	.92	.37	.09	1737	507	30.09
505	160-$\frac{25}{45}$-F	99.96	1.40	.41	.12	1703	507	34.66
506	160-$\frac{25}{45}$-F	180	.84	.65	.14	1872	509	37.71
510	240-$\frac{25}{45}$-F	120	1.64	.82	.13	1737	558	52.74
511	240-$\frac{30}{55}$-F	120	3.13	1.03	.07	——	582	71.74
507	160-$\frac{40}{60}$-F	180	2.42	.85	.12	1873	594	67.81
512	240-$\frac{35}{60}$-F	120	3.56	1.04	.08	——	586	79.09
513	280-$\frac{35}{55}$-F	74.40	3.27	1.08	.09	2044	581	86.77
508	160-$\frac{50}{60}$-F	180	3.53	1.52	.40	1818	591	91.00

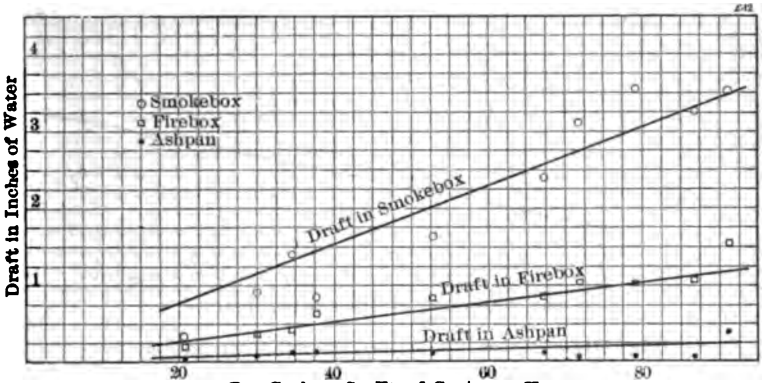


Fig. 502.— Draft and Rate of Combustion.

the fire-box temperatures increased at a slightly greater rate than the smoke-box temperatures.

EVAPORATIVE PERFORMANCE—TABLE 507.

The equivalent evaporation per pound of dry coal ranged from 12.19 pounds to 7.9 pounds.

The heating value of the coal was practically uniform for all the tests. The efficiency of the boiler dropped as the rate of evaporation increased, the range being between the limits of 78.55 per cent. and 51.35 per cent.

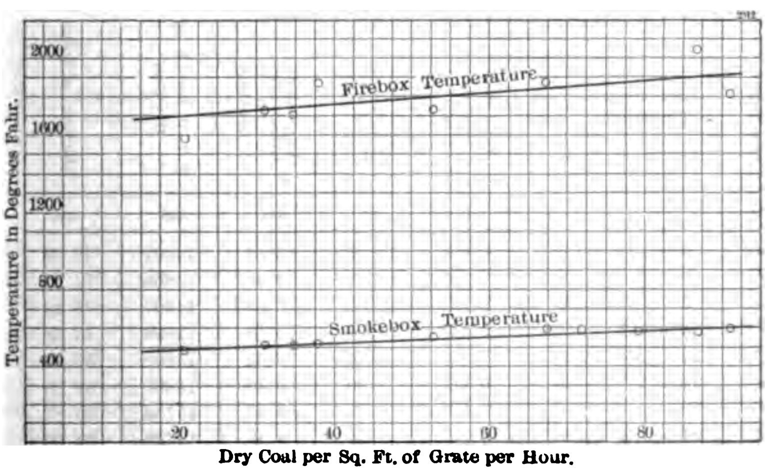


Fig. 503.— Fire-box and Smoke-box Temperatures.

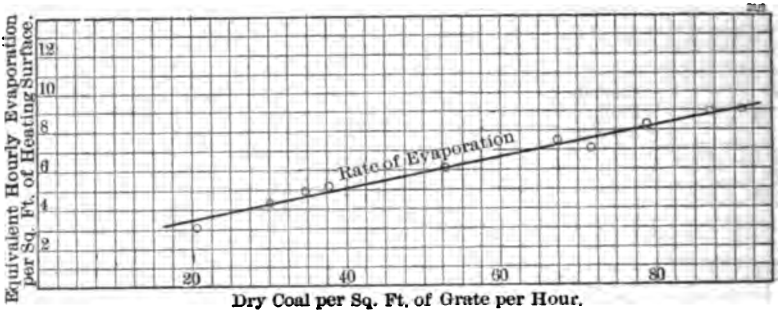


Fig. 504.— Rates of Combustion and Evaporation.

From Fig. 505 the relation between H and E was found to be:

$$E = 13.8 - .646H \quad \text{.........................} (509)$$

SMOKE-BOX GASES—TABLE 508.

The percentage of oxygen ranged from 8.63 per cent. to 4.93 per cent.

The CO ranged from .0 to 1.03 per cent.

The carbon dioxide, CO_2, ranged from 9.97 per cent. to 12.66 per cent.

The heat lost by imperfect combusion ranged from 0 to 4.43 per cent.

TABLE No. 507—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
501	80–$\frac{25}{45}$–F	180	10.14	12.19	13.01	14991	78.55
502	80–$\frac{35}{60}$–F	109.5	9.62	11.53	12.40	14866	74.88
505	160–$\frac{25}{45}$–F	99.96	9.41	11.31	12.08	14907	73.29
506	160–$\frac{25}{45}$–F	180	9.17	10.97	11.58	14983	70.68
510	240–$\frac{25}{45}$–F	120	7.67	9.24	9.92	14892	59.93
511	240–$\frac{30}{35}$–F	120	6.46	7.90	8.49	14867	51.35
507	160–$\frac{10}{60}$–F	180	7.32	8.94	9.42	15183	56.87
512	240–$\frac{35}{60}$–F	120	6.84	8.36	9.19	14426	55.99
513	280–$\frac{30}{35}$–F	74.40	6.62	8.10	8.58	15185	51.48
508	160–$\frac{10}{60}$–F	180	6.58	7.90	8.40	14858	51.35

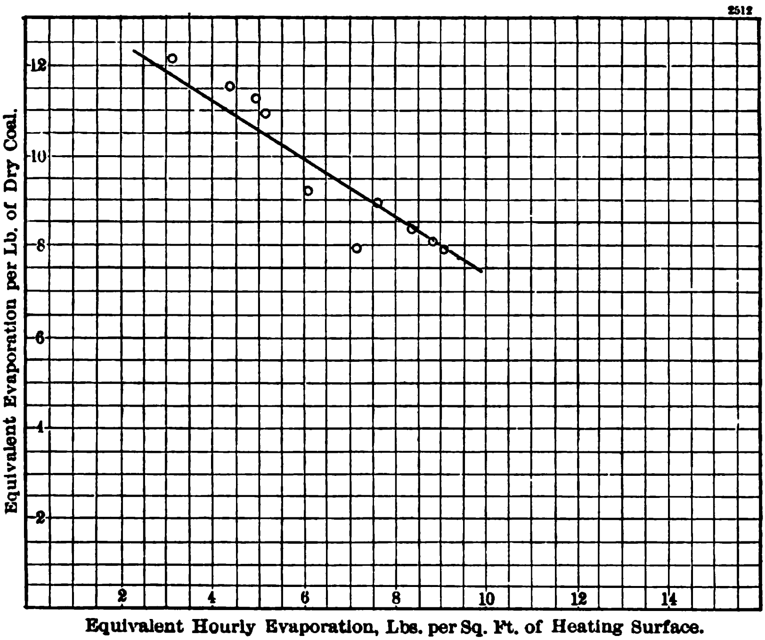


Fig. 505.— Rate of Evaporation and Evaporation per Lb. of Coal.

TABLE No. 508—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
501	80-$\frac{25}{45}$-F	180	——	——	——	——	——	——
502	80-$\frac{35}{60}$-F	109.5	——	——	——	——	——	——
505	160-$\frac{25}{45}$-F	99.96	6.40	.0	12.25	81.35	14747	.0
506	160-$\frac{25}{45}$-F	180	4.93	.16	12.66	82.25	14857	.72
510	240-$\frac{25}{45}$-F	120	8.30	.15	10.80	80.75	14732	.79
511	240-$\frac{30}{55}$-F	120	7.57	.17	10.80	81.46	14720	.90
507	160-$\frac{40}{60}$-F	180	7.65	.25	10.70	81.40	15039	1.29
512	240-$\frac{35}{60}$-F	120	7.83	.10	11.03	81.54	14298	.54
513	280-$\frac{30}{55}$-F	74.40	8.63	.23	9.97	81.17	15040	1.28
508	160-$\frac{50}{70}$-F	180	5.50	1.03	12.47	81.00	14720	4.43

TABLE No. 509—GENERAL ENGINE CONDITIONS.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke H. P. Cylinder	Cut-off Per Cent. of Stroke L. P. Cylinder	Steam Pressure: In Boiler Lbs. Per Sq. In.	Steam Pressure: In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	Cal.	217	220
501	80–$\frac{25}{45}$–F	180	80.00	19.13	26.9	52.1	212.0	208.7
502	80–$\frac{35}{60}$–F	109.5	80.05	19.14	39.1	60.0	215.2	210.8
505	160–$\frac{25}{45}$–F	99.96	159.96	38.25	25.2	52.3	219.7	215.2
506	160–$\frac{25}{45}$–F	180	160.00	38.26	27.3	52.7	219.6	214.7
507	160–$\frac{40}{60}$–F	180	160.00	38.26	38.4	60.1	214.6	206.2
508	160–$\frac{50}{70}$–F	180	160.00	38.26	49.7	69.8	206.4	200.4
510	240–$\frac{25}{45}$–F	120	240.00	57.39	27.7	50.0	212.5	209.6
511	240–$\frac{30}{55}$–F	120	240.00	57.39	29.8	57.2	218.9	209.7
512	240–$\frac{35}{60}$–F	120	239.99	57.39	34.2	62.2	217.5	207.1
513	280–$\frac{30}{55}$–F	74.40	279.99	66.96	29.2	57.9	215.0	204.4

TABLE No. 510—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

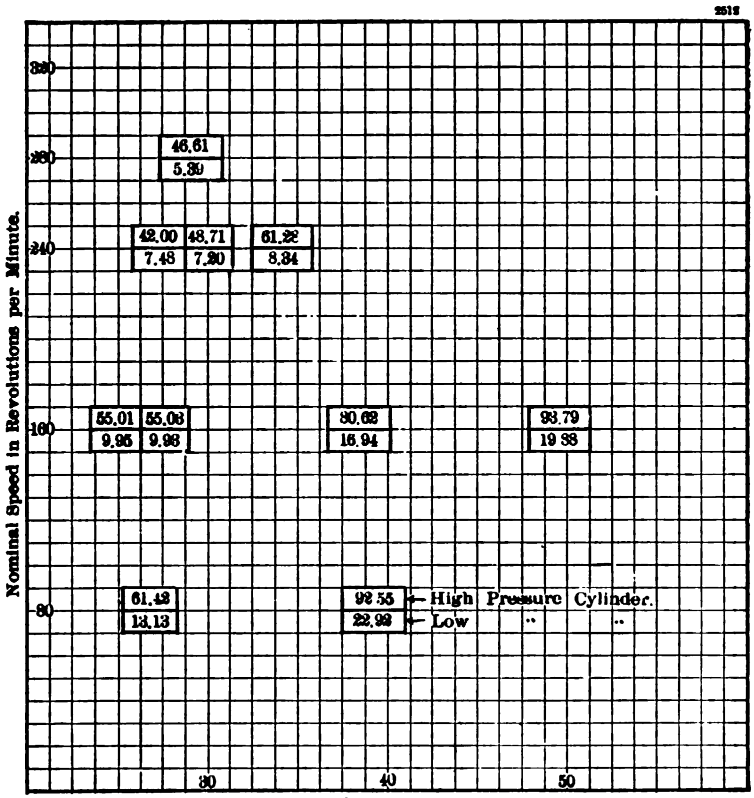
Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch: H. P. Cyl.	Mean Effective Pressure Lbs. Per Sq. Inch: L. P. Cyl.	Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
		Cal.	Cal.	Cal.	379	381
501	80–$\frac{25}{45}$–F	180	61.4	13.1	310.4	21.20
502	80–$\frac{35}{60}$–F	109.5	92.6	22.9	495.7	18.60
505	160–$\frac{25}{45}$–F	99.96	55.0	10.0	524.5	19.95
506	160–$\frac{25}{45}$–F	180	55.0	9.9	524.5	21.15
507	160–$\frac{40}{60}$–F	180	80.6	16.9	809.3	19.60
508	160–$\frac{50}{70}$–F	180	93.8	19.9	944.6	20.67
510	240–$\frac{25}{45}$–F	120	42.0	7.5	596.8	21.95
511	240–$\frac{30}{55}$–F	120	48.7	7.2	653.2	22.69
512	240–$\frac{35}{60}$–F	120	61.3	8.3	802.3	21.62
513	280–$\frac{30}{55}$–F	74.40	46.6	5.4	682.5	27.05

PERFORMANCE OF ENGINES.

The results in Tables 509 and 510 are arranged with reference to the speed of the locomotive, the tests at each speed being grouped.

GENERAL ENGINE CONDITIONS—TABLE 509.

The lowest speed at which any test was run was 19.13



Cut-off in Percent, High Pressure Cylinders.

Fig. 506.— Mean Effective Pressure.

miles per hour, while the highest speed was 66.96 miles per hour.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 510.

The best performance of the engines was 18.6 pounds of dry steam per indicated horse power hour which was obtained at a speed of 80.05 revolutions per minute and a cut-off of 39.1 and 60 per cent. in the high and low pressure cylinders respectively.

The highest indicated horse power was 944.6, which was obtained at 49.7 per cent. high-pressure cut-off and 69.8 per cent. low-pressure cut-off and a speed of 160 revolutions per minute.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 511.

The maximum average recorded draw-bar pull was 8,615

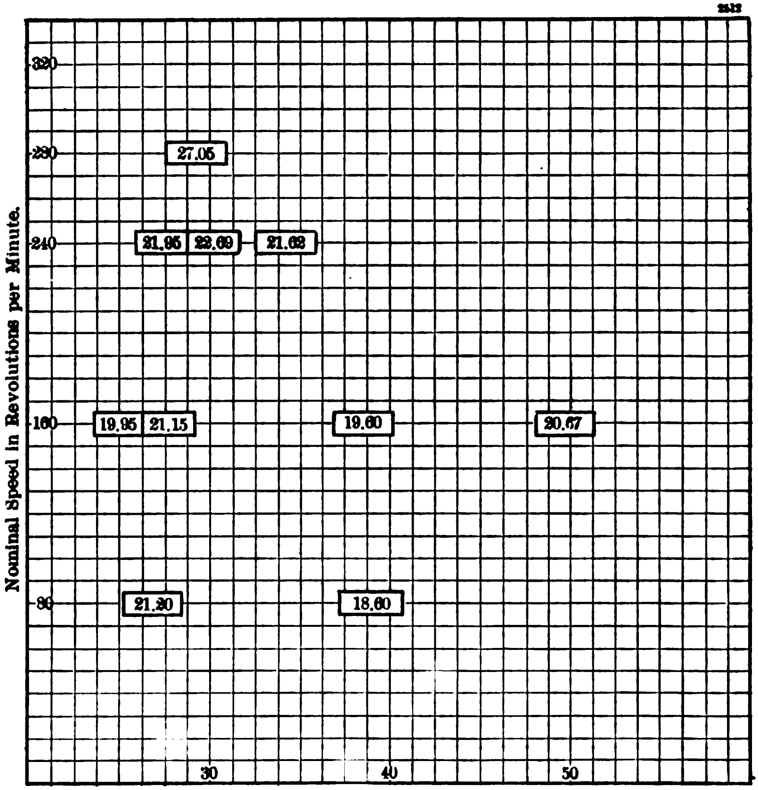


Fig. 507.— Dry Steam per I. H. P, Hour.

pounds at a nominal speed of 80 revolutions per minute and a nominal cut-off of 35 and 60 per cent. in the high and low pressure cylinders respectively. Higher draw-bar pulls were not obtained because it was thought that for a passenger locomotive, tests at maximum draw-bar pulls at higher speeds, where the limiting factor is the steaming capacity of the boiler rather than adhesion, would be of greater interest than tests near adhesive limits. The same danger from stalling the brakes existed, as with the freight locomotives, but to a smaller degree.

The maximum dynamometer horse power was 842.9, which was obtained at a speed of 160 revolutions per minute and a cut-

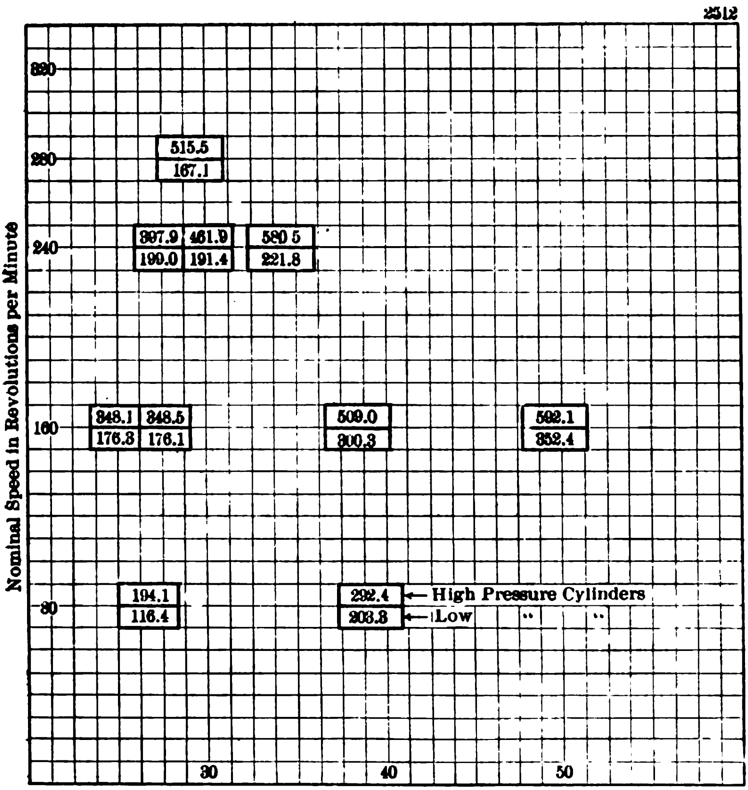


Fig. 508.— Total Indicated Horse Power.

off of 50 and 70 per cent. in the high and low-pressure cylinders respectively.

The general tendency was for the coal per dynamometer horse power hour to increase as the speed increased. The minimum coal rate obtained was 2.19 pounds and the maximum 5.48 pounds per dynamometer horse power hour.

The lowest steam consumption was 20.96 pounds per dynamometer horse power hour, which was obtained at a speed of 80

TABLE No. 511—DYNAMOMETER RECORDS.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D. H. P. Hour
		Cal.	265	383	384	385
501	80–$\frac{25}{45}$–F	180	5443	277.7	2.34	23.70
502	80–$\frac{35}{60}$–F	109.5	8615	439.7	2.19	20.96
505	160–$\frac{25}{45}$–F	99.96	4343	443.0	2.52	23.77
506	160–$\frac{25}{45}$–F	180	4448	453.8	2.67	24.45
507	160–$\frac{40}{60}$–F	180	5976	609.7	3.57	26.01
508	160–$\frac{50}{70}$–F	180	8262	842.9	3.52	23.16
510	240–$\frac{25}{45}$–F	120	2309	353.4	4.83	37.06
511	240–$\frac{30}{55}$–F	120	3664	560.7	4.10	26.42
512	240–$\frac{35}{60}$–F	120	4268	653.1	3.90	26.56
513	280–$\frac{30}{55}$–F	74.40	2857	510.1	5.48	36.19

TABLE No. 512—MACHINE FRICTION.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Machine Friction in: Horse Power	Machine Friction in: Draw-Bar Pull Pounds	Machine Efficiency Per Cent.
		Cal.	395	397	398
501	80–$\frac{25}{45}$–F	180	32.76	642	89.45
502	80–$\frac{35}{60}$–F	109.5	55.95	1096	88.71
	Average		44.35	869	
505	160–$\frac{25}{45}$–F	99.96	81.49	799	84.46
506	160–$\frac{25}{45}$–F	180	70.70	693	86.52
507	160–$\frac{40}{60}$–F	180	199.53	1956	75.35
508	160–$\frac{50}{70}$–F	180	101.67	997	89.23
	Average		113.35	1111	
510	240–$\frac{25}{45}$–F	120	243.42	1591	59.22
511	240–$\frac{30}{55}$–F	120	92.47	604	85.85
512	240–$\frac{35}{60}$–F	120	149.25	976	81.41
	Average		161.71	1057	
513	280–$\frac{30}{55}$–F	74.40	172.38	966	74.74

revolutions per minute and a cut-off of 35 and 60 per cent. in the high and low pressure cylinders respectively.

MACHINE FRICTION—TABLE 512.

The average values of the frictional horse power for nominal speeds of 80, 160, 240 and 280 revolutions per minute were 44.35, 113.35, 161.71 and 172.38 respectively, and the draw-bar pull equivalents of these horse powers at the same speeds are respectively 869, 1,111, 1,057 and 966 pounds.

The machine efficiency ranged from 74.74 per cent. to 89.45 per cent.

MAXIMUM POWER OF LOCOMOTIVE.

The maximum evaporative power of the boiler, as disclosed by these tests, is between 19,000 and 20,000 pounds of steam per hour.

By applying the method explained in full in Chapter XIII, page 143, the maximum draw-bar pull of this locomotive at different speeds, as limited by the adhesive weight and the maximum evaporation, has been obtained.

The critical cut-off, the steam consumption and the maximum cylinder horse power, for the several speeds, as disclosed by Figs. 509 and 510, are given in the following table:

Nominal Speed in R. P. M.	Cut-off in Per Cent.	Steam per Indicated Horse Power Hour.	Maximum Cylinder Horse Power.
80	81.5	22.4	890
160	53	20.3	980
240	44	21.7	920
280	32	26.8	740

The difference between the maximum cylinder horse power

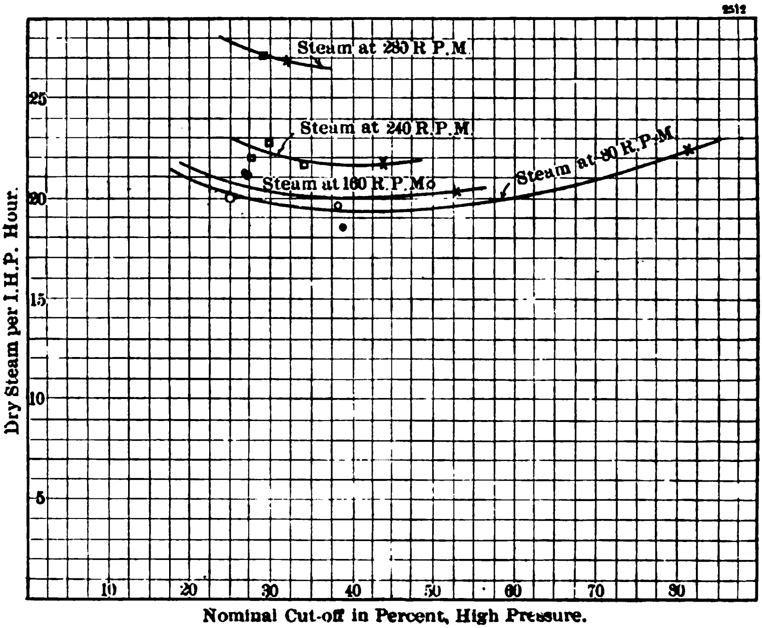


Fig. 509.— Steam Consumption.

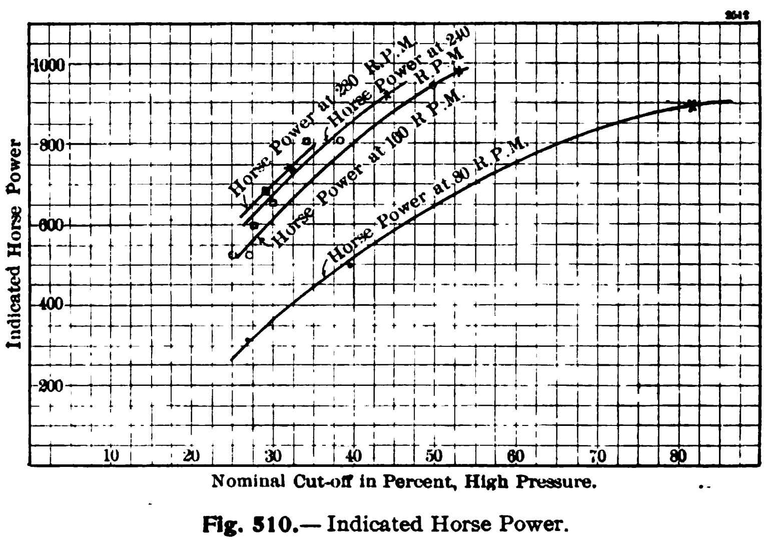


Fig. 510.— Indicated Horse Power.

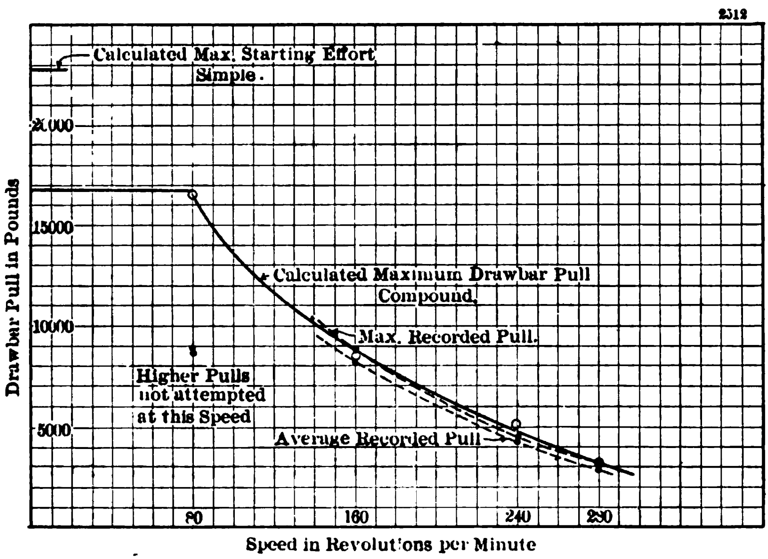


Fig. 511.— Maximum Draw-Bar Pull.

and the frictional horse power reduced to the equivalent draw-bar pull at the several speeds, is given in the following table:

Speeds in R. P. M.	Maximum Estimated Draw-Bar Pull, Pounds.
80	16570
160	8494
240	5129
280	3180

The diagram, Fig. 511, shows that the lowest speed at which the full power of the boiler can be utilized is 80 revolutions per minute.

APPENDIX 500.

The appendix contains:

1. Description, dimensions and proportions of the locomotive. (pp. 413 to 418 inclusive.)

2. Summary of average results of tests. (pp. 419 to 429 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 430 to 434 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 435 to 450 inclusive.)

5. Vibration diagrams. (pp. 451 to 454 inclusive.)

6. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 455 to 458 inclusive.)

7. A typical dynamometer diagram for each nominal speed. (pp. 459 to 461.)

8. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of Pennsylvania DeGlehn Atlantic (4-4-2) Type Locomotive No. 2512.

Built by the Societe Alsacienne de Constructions Mecaniques, Belfort, France, 1904.

DRIVING WHEELS.

1	Number of pairs	2
2	Approximate diameter, inches	80

MEASURED CIRCUMFERENCE, FEET.

3	Right, No. 1	21.043
4	“ “ 2	21.043
5	“ “ 3	——
6	“ “ 4	——
7	“ “ 5	——
8	Left, “ 1	21.043
9	“ “ 2	21.043
10	“ “ 3	——
11	“ “ 4	——
12	“ “ 5	——
13	Average	21.043

ENGINE TRUCK WHEELS.

14	Number	4
15	Diameter, inches	37.824

TRAILING WHEELS.

16	Diameter, inches	60.780

WHEEL BASE, FEET.

17	Driving wheel base	7.058
18	Total wheel base	28.569
19	Gauge of wheels, in inches	54.844

WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.

20	On truck	41,250
21	“ 1st drivers	44,550
22	“ 2nd “	43,300
23	“ 3rd “	——
24	“ 4th “	——
25	“ 5th “	——
26	“ trailers	34,900
27	Total	164,000
28	“ on drivers	87,850

CYLINDERS.

29	High pressure, number	2
30	Low “ “	2
31	Arrangement	L. P. inside; H. P. outside; De Glehn

DIAMETER, INCHES.

32	High pressure, right	14.1847
33	" " left	14,1834
34	Low " right	23.6550
35	" " left	23.6536

STROKE OF PISTON, FEET.

36	High pressure, right	2.0975
37	" " left	2.0975
38	Low " right	2.1025
39	" " left	2.1050

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P., right, head end	13.59
41	" " crank "	13.02
42	" left, head "	13.83
43	" " crank "	12.65
44	L. P., right, head "	9.92
45	" " crank "	9.12
46	" left, head "	11.27
47	" " crank "	8.68

RECEIVER, CUBIC FEET.

48	Volume, right side	14.52
49	" left "	

STEAM PORTS, INCHES.

(For piston valves the length equals the circumference of inside of bushing minus the sum of the widths of bridges.)

50	H. P. admission, right, head end, length	13.492
51	" " " " " width	1.400
52	" " " crank " length	13.438
53	" " " " " width	1.405
54	" " left, head " length	13.374
55	" " " " " width	1.409
56	" " " crank " length	13.500
57	" " " " " width	1.400
58	L. P. " right, head " length	19.934
59	" " " " " width	1.700
60	" " " crank " length	19.975
61	" " " " " width	1.696
62	" " left, head " length	19.882
63	" " " " " width	1.700
64	" " " crank " length	19.959
65	" " " " " width	1.700
66	H. P. exhaust, right, length	13.562
67	" " " width	3.162
68	" " left, length	13.579
69	" " " width	3.160
70	L. P. " right, length	20.004

71	L. P. exhaust, right, width	3.153
72	" " left, length	20.012
73	" " " width	3.157

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	2.6763
75	" " left	2.6769
76	Low " right	2.6755
77	" " left	2.6759

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	none
79	" " left	none
80	Low " right	2.3609
81	" " left	2.3610

VALVES.

82	Type	"D" Slide
83	Design	L. P. not balanced; H. P. balance ring
84	Per cent. of balanced to total area	H. P. valve 40.92
85	Type of link motion	Walschaert

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	5.25
87	" " left	5 28
88	Low " right	5.29
89	" " left	5.31

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure, right, head end	1.050
91	" " " crank "	1.050
92	" " left, head "	1.055
93	" " " crank "	1.055
94	Low " right, head "	1.060
95	" " " crank "	1.060
96	" " left, head "	1.0725
97	" " " crank "	1.0725

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	negative	.120
99	" " " crank "	"	.120
100	" " left, head "	"	.120
101	" " " crank "	"	.120
102	Low " right, head "	"	.200
103	" " " crank "	"	.190
104	" " left, head "	"	.207
105	" " " crank "	"	.207

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	Sheet iron
108	Lead, forward motion	H. P., .3125; L. P., .3125
109		
110	Right L. P. crank leads left L. P. crank	
111		
112		

BOILER.

113	Type	Belpaire, straight top
114	Outside diameter, 1st ring, inches	59.664

TUBES.

115	Number	139
116	Outside diameter, inches	2.75
117	Thickness, inches	.075
118	Length between tube sheets, inches	176.136
119	Total fire area, square feet	4.691
120	Serve tubes, number of ribs	8.
121	" " sq. in. of inside surface in one in. of length	14.968
122		
123		
124	Boiler pressure, pounds per sq. in.	225

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129		
130		
131		

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	119.88
133	Width	39.66
134	Depth, front end	76.44
135	" back "	55.80
136	Volume, cubic feet (less arch)	170.21
137	Air inlets to ash pan (dampers closed) sq. ft.	0.00
138	" " " " " (" open) " "	4.75
139		
140		

FIRE DOORS.

141	Number	1
142	Area, square feet	1.221
143	Width in inches	16.500

GRATES.

144	Style	Stationary, wrought iron bars
145	Total area, square feet	33.39
146	" " dead grates, square feet	0
147	Width of air spaces, inches	.50

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	0
149	" grates	17.380
150	" fire doors	.122
151	Total air inlets, (148), (149) and (150)	17.502
152	Ratio " " (149) to grate area (145)	.521
153	" " " (151) " " " (145)	.524

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	1468.87
155	" " " fire "	2479.20
156	" " firebox, fire side	177.28
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	2656.48
159	Total, based on inside of firebox and outside of tubes	1646.15

BOILER VOLUMES.

(*With water surface at level of second gauge cock.*)

160	Water space, cubic feet	220.16
161	Steam " " "	75.69

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	variable
164	" " left, "	variable
165	Area of right, square inches	——
166	" " left, " "	——
167	Total area, square inches	Max. 43.5, min. 17.5

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	52
169	L. P. " " " " "	47
170	Screw reverse	H. P. and L. P. independent

RATIOS.

171	Heating surface (158) to grate area (145)......	79.56
172	Fire area through tubes (119) to grate area (145)	.14
173	Firebox heating surface (156) to grate area (145)	5.31
174	Tube surface (155) to firebox heating surface (156)..	13.98
175	Firebox volume (136) to grate area (145)......	5.10
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(*power developed at one R. P. M. when pull is one pound.*)

179 .... .00063767

CONSTANTS FOR INDICATED HORSE POWER

(*power developed at one R. P. M. and one pound M. E. P.*)

180	High	pressure	cylinder,	right,	head	end	.010044
181	"	"	"	"	crank	"	.009686
182	"	"	"	left,	head	"	.010042
183	"	"	"	"	crank	"	.009685
184	Low	"	"	right,	head	"	.027721
185	"	"	"	"	crank	"	.027642
186	"	"	"	left,	head	"	.027751
187	"	"	"	"	crank	"	.027671

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head	end	2.3020
189	"	"	"	"	crank	"	2.2199
190	"	"	"	left,	head	"	2.3014
191	"	"	"	"	crank	"	2.2190
192	Low	"	"	right,	head	"	6.3520
193	"	"	"	"	crank	"	6.3340
194	"	"	"	left,	head	"	6.3595
195	"	"	"	"	crank	"	6.3413

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed: Revolutions: Total	Speed: Revolutions: Average Per Minute	Speed: Equivalent: Speed in Miles Per Hour	Speed: Equivalent: Piston Speed in Feet Per Minute	Position of Levers: Reverse, Notches from Front End H. P.	Position of Levers: Reverse Notches from Front End L. P.	Position of Levers: Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	Area of Exhaust Nozzle Sq. Inches
		196	197	198	199	200	201	202	203	204	205
501	80–$\frac{25}{45}$–F	3.000	14400	80.00	19.13	336.1	42	28	FULL	41	16.5
502	80–$\frac{35}{60}$–F	1.825	8765	80.05	19.14	336.3	38	17	"	44	18.3
505	160–$\frac{25}{45}$–F	1.666	14397	159.96	38.25	672.1	43	28	"	45	21.5
506	160–$\frac{25}{45}$–F	3.000	28800	160.00	38.26	672.7	43	28	"	47	21.5
507	160–$\frac{40}{60}$–F	3.000	28800	160.00	38.26	672.7	34	17	"	73	19.8
508	160–$\frac{50}{70}$–F	3.000	28800	160.00	38.26	672.7	30	8	"	70	16.5
510	240–$\frac{25}{45}$–F	2.000	28800	240.00	57.39	1008.3	43	27	"	54	17.5
511	240–$\frac{30}{55}$–F	2.000	28800	240.00	57.39	1008.3	40	21	"	97	18.1
512	240–$\frac{35}{60}$–F	2.000	28799	239.99	57.39	1008.2	37	18	"	98	18.1
513	280–$\frac{30}{55}$–F	1.240	23799	279.99	66.96	1176.1	40	21	"	101	18.1

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of: Smoke Box: By Thermometer	Smoke Box: By Pyrometer	Laboratory: Dry Bulb	Laboratory: Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer		Horizontal Vibration at Front of Engine Inches	Horizontal Vibration at Back of Engine Inches	Steam lost from Boiler, etc. Lbs. per hour
		206	207	208	209	210	211	212	213	214	215	216
501	80–$\frac{25}{45}$–F	473	483	78.1	71.5	391.1	69.4	1588		.12	.14	414
502	80–$\frac{35}{60}$–F	487	507	76.7	71.7	391.9	71.7	1737		—	—	419
505	160–$\frac{25}{45}$–F	494	507	83.4	76.9	393.5	72.5	1703		.09	.07	427
506	160–$\frac{25}{45}$–F	503	509	84.0	76.7	393.4	74.7	1872		—	—	427
507	160–$\frac{40}{60}$–F		594	36.8	33.4	390.2	47.4	1873		—	—	529
508	160–$\frac{50}{70}$–F	577	591	72.9	63.6	387.8	71.9	1818		.11	.08	460
510	240–$\frac{25}{45}$–F	—	558	56.0	44.8	391.5	68.8	1737		.20	.15	416
511	240–$\frac{30}{55}$–F	—	582	48.4	42.1	391.5	47.0	—		.30	—	622
512	240–$\frac{35}{60}$–F	—	586	52.0	44.8	390.4	47.2	—		.32	—	667
513	280–$\frac{30}{55}$–F	—	581	52.4	44.4	389.4	47.0	2044		.30	—	663

For date of test, see item 407.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	In Boiler: Maximum	In Boiler: Minimum	In Branch Pipe	Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box	In Smoke Box	In Fire Box	In Ash Pan	Injectors: Hours in Action: Total, Right	Total, Left
		217	218	219	220	221	222	223	224	225	226	227
501	80-$\frac{25}{45}$-F	212.0	216.5	207.0	208.7	14.581	.33		.21	.04	.943	0
502	80-$\frac{35}{60}$-F	215.2	220.5	205.5	210.8	14.498	.92		.37	.09	.894	0
505	160-$\frac{25}{45}$-F	219.7	224.5	213.5	215.2	14.373	1.40		.41	.12	1.001	0
506	160-$\frac{25}{45}$-F	219.6	223.0	215.0	214.7	14.458	.84		.65	.14	1.868	0
507	160-$\frac{40}{60}$-F	214.6	219.0	205.3	206.2	14.691	2.42		.85	.12	0	2.94
508	160-$\frac{50}{70}$-F	206.4	224.0	147.0	200.4	14.488	3.53		1.52	.40	2.898	0
510	240-$\frac{25}{45}$-F	212.5	216.8	205.0	209.6	14.595	1.64		.82	.13	1.425	0
511	240-$\frac{30}{55}$-F	218.9	220.8	215.2	209.7	14.445	3.13		1.03	.07	.063	1.907
512	240-$\frac{35}{60}$-F	217.5	220.1	210.7	207.1	14.417	3.56		1.04	.08	0	1.996
513	280-$\frac{30}{55}$-F	215.0	219.3	209.2	204.4	14.429	3.27		1.08	.09	0	1.418

Test Number	Laboratory Designation	Quality of steam: In Dome	In Branch Pipe	Degrees of Superheat in Branch Pipe	Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Coal Fired: Kind	Coal Fired: Total	Coal Fired: Per Cent of Moisture	Total: Dry Coal Fired	Total: Combustible by Analysis	Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
501	80-$\frac{25}{45}$-F	.9851	.9863	0	.98929	Bituminous	2090	.90	2071	1937	133
502	80-$\frac{35}{60}$-F	.9845	.9865	0	.98885	"	1849	.81	1834	1705	129
505	160-$\frac{25}{45}$-F	.9849	.9863	0	.98920	"	1950	1.08	1929	1806	123
506	160-$\frac{25}{45}$-F	.9843	.9863	0	.98871	"	3810	.85	3778	3578	200
507	160-$\frac{40}{60}$-F	.9815	.9880	0	.98698	"	6807	.96	6742	6401	340
508	160-$\frac{50}{70}$-F	.9859	.9874	0	.98980	"	9202	.94	9116	8634	481
510	240-$\frac{25}{45}$-F	.9842	.9841	0	.98865	"	3561	1.10	3522	3280	242
511	240-$\frac{30}{55}$-F	.9813	.9881	0	.98686	"	4839	1.00	4791	4462	328
512	240-$\frac{35}{60}$-F	.9815	.9883	0	.98700	"	5331	.93	5282	4810	472
513	280-$\frac{30}{55}$-F	.9812	.9885	0	.98677	"	3628	.97	3593	3389	204

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs — Total — Cinders Collected in Smoke Box	Sparks Discharged From Stack	Cinders and Sparks	Analysis of Coal — Per Cent — Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
501	80-25/40-F	127	17	144	75.48	17.24	.90	6.38	1.19		
502	80-35/60-F	124	18	142	74.63	17.61	.81	6.95	1.10		
505	160-25/45-F	149	32	181	74.99	17.64	1.08	6.29	1.00		
506	160-25/45-F	201	24	225	76.96	16.95	.85	5.24	.73		
507	160-40/60-F	462	60	522	77.63	16.41	.96	5.00	.80		
508	160-50/70-F	2135	345	2480	76.84	16.99	.94	5.23	.94		
510	240-25/45-F	2411	42	2453	74.71	17.40	1.10	6.79	1.05		
511	240-30/50-F	255	34	289	75.99	16.23	1.00	6.78	.81		
512	240-35/60-F	438	62	500	73.57	16.65	.93	8.85	1.39		
513	280-30/55-F	306	41	347	76.80	16.61	.97	5.62	1.05		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B.T.U. — Of Dry Coal	Of Combustible	Of Cinders	Of Sparks		Analysis of Smoke Box Gases — Per Cent — Oxygen O	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
501	80-25/40-F	14991	16022	——	——		——	—	——	——		
502	80-35/60-F	14866	15986	——	——		——	—	——	——		
505	160-25/45-F	14907	15912	——	——		6.40	.0	12.25	81.35		
506	160-25/45-F	14983	15819	11224	10844		4.93	.16	12.66	82.25		
507	160-40/60-F	15183	15829	12799	12372		7.65	.25	10.70	81.40		
508	160-50/70-F	14858	15686	12585	11519		5.50	1.03	12.47	81.00		
510	240-25/45-F	14892	15979	10666	8959		8.30	.15	10.80	80.75		
511	240-30/50-F	14867	15960	13012	12799		7.57	.17	10.80	81.46		
512	240-35/60-F	14426	15841	13225	12799		7.33	.10	11.03	81.54		
513	280-30/55-F	15185	16099	13225	12372		8.63	.23	9.97	81.17		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Water, in Pounds: Delivered to Injectors	Water, in Pounds: Lost: From Boiler	Water, in Pounds: Lost: From Injectors	Water, in Pounds: Lost: From	Water, in Pounds: Lost: Total	Water, in Pounds: Delivered to Boiler and Presumably Evaporated	Dynamometer: Drawbar Pull in Pounds: Average	Dynamometer: Drawbar Pull in Pounds: Maximum	Dynamometer: Drawbar Pull in Pounds: Minimum
		259	260	261	262	263	264	265	266	267
501	80-$\frac{25}{45}$-F	23980	0	2782		2782	21198	5443	5630	5140
502	80-$\frac{35}{60}$-F	17779	0	0		0	17779	8615	8982	7545
505	160-$\frac{25}{45}$-F	18437	0	90		90	18347	4343	4692	4068
506	160-$\frac{25}{45}$-F	35480	0	540		540	34940	4448	4530	4268
507	160-$\frac{40}{60}$-F	50283	0	485		485	49798	5976	6092	5596
508	160-$\frac{50}{70}$-F	60732	0	180		180	60552	8262	8982	6740
510	240-$\frac{25}{45}$-F	27713	0	390		390	27323	2309	2407	2156
511	240-$\frac{30}{55}$-F	31319	0	46		46	31273	3664	3978	3559
512	240-$\frac{35}{60}$-F	36540	0	58		58	36482	4268	4410	4130
513	280-$\frac{30}{55}$-F	24077	0	54		54	24023	2857	3178	2482

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards: Cut-off, Per Cent. of Stroke: High Pressure Cylinder: Right Side: Head End	Crank End	High Pressure Cylinder: Left Side: Head End	Crank End	Low Pressure Cylinder: Right Side: Head End	Crank End	Low Pressure Cylinder: Left Side: Head End	Crank End	Release, Per Cent. of Stroke: High Pressure Cylinder: Right Side: Head End	Crank End	High Pressure Cylinder: Left Side: Head End	Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
501	80-$\frac{25}{45}$-F	31.3	——	27.1	22.4	50.9	52.8	52.5	——	66.7	——	63.6	56.4
502	80-$\frac{35}{60}$-F	43.0	——	38.8	35.6	60.4	59.3	61.3	58.9	74.3	——	71.8	68.4
505	160-$\frac{25}{45}$-F	32.7	14.4	28.8	24.7	52.4	52.2	——	——	68.2	56.0	62.0	59.5
506	160-$\frac{25}{45}$-F	35.9	15.0	32.1	26.0	52.9	52.9	58.7	51.3	69.1	55.9	63.5	59.4
507	160-$\frac{40}{60}$-F	39.7	35.2	41.2	37.6	60.3	58.7	62.7	58.7	76.8	72.9	77.5	74.1
508	160-$\frac{50}{70}$-F	52.3	45.8	53.3	47.5	69.6	69.9	72.1	67.4	79.7	74.6	80.5	75.2
510	240-$\frac{25}{45}$-F	30.1	25.5	29.5	25.6	51.8	46.6	51.9	49.8	64.8	62.1	66.5	59.3
511	240-$\frac{30}{55}$-F	31.2	27.8	31.5	28.8	57.0	57.2	59.4	55.3	70.0	66.7	71.1	69.0
512	240-$\frac{35}{60}$-F	33.8	32.8	36.8	33.5	61.7	60.5	64.4	62.0	72.3	70.6	70.3	71.6
513	280-$\frac{30}{55}$-F	27.3	25.8	32.6	31.0	57.6	57.5	59.2	57.1	72.0	68.3	74.1	71.5

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512, PENNSYLVANIA RAILROAD COMPANY,

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
501	80-25/45-F	76.8	74.7	77.8	——	43.1	——	37.8	33.0	25.3	22.1	24.9	——
502	80-35/60-F	82.9	81.8	84.2	80.5	37.0	——	31.1	25.2	18.9	15.4	18.2	14.5
505	160-25/45-F	72.9	73.4	——	——	43.4	31.6	35.2	34.0	30.3	24.7	——	——
506	160-25/45-F	73.8	74.0	74.0	72.8	42.2	31.2	36.6	33.0	28.1	23.7	27.3	25.2
507	160-40/60-F	85.3	82.8	85.6	82.8	32.4	29.7	32.6	29.1	20.4	17.3	20.5	16.3
508	160-50/70-F	86.3	85.1	87.5	83.7	27.3	21.4	26.4	20.9	16.8	13.6	14.5	13.1
510	240-25/45-F	72.7	71.8	75.1	73.4	40.6	38.0	41.2	35.8	32.3	30.9	33.2	30.1
511	240-30/55-F	76.1	76.3	78.1	75.2	38.2	37.7	38.8	37.2	26.5	23.2	24.2	21.0
512	240-35/60-F	81.8	81.3	84.6	82.1	35.5	37.2	37.3	35.5	22.7	19.8	21.7	18.1
513	280-30/55-F	75.0	76.0	77.6	74.9	40.1	40.1	40.4	41.4	27.0	25.5	24.4	20.9

Test Number	Laboratory Designation	Pressures from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
501	80-25/45-F	214.2	——	212.0	219.0	26.8	26.1	26.1	——	1.2039
502	80-35/60-F	215.4	——	214.3	213.6	33.9	31.2	32.0	31.9	1.2020
505	160-25/45-F	226.2	149.2	224.5	214.3	27.1	22.2	——	——	1.2020
506	160-25/45-F	223.2	151.0	222.6	214.0	25.6	21.0	25.5	25.9	1.1994
507	160-40/60-F	209.2	209.8	207.3	210.5	29.9	30.3	30.3	30.3	1.2263
508	160-50/70-F	202.3	199.4	200.6	197.8	34.5	34.0	31.6	34.2	1.2012
510	240-25/45-F	209.7	194.5	212.5	212.1	30.2	30.3	30.2	29.6	1.2046
511	240-30/55-F	218.1	206.9	214.8	208.2	35.9	43.6	39.1	41.0	1.2270
512	240-35/60-F	214.3	193.9	210.2	206.0	37.4	41.6	38.1	38.3	1.2268
513	280-30/55-F	219.0	196 0	210.0	201.0	45.7	49.9	46.4	44.0	1.2269

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Pressures from Indicator Cards: Steam Chest Pressures, Pounds Per Square Inch: High Pressure: Right Side	High Pressure: Left Side	Low Pressure: Right Side	Low Pressure: Left Side		Pressures at Cut-off, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		301	302	303	304	305	306	307	308	309
501	80–$\frac{25}{45}$–F	——	219.0	——	——		166.5	——	165.9	165.8
502	80–$\frac{35}{60}$–F	——	——	——	34.5		180.0	——	179.1	176.5
505	160–$\frac{25}{45}$–F	217.9	218.9	——	——		158.8	187.2	153.0	152.0
506	160–$\frac{25}{45}$–F	218.2	222.4	——	25.9		145.6	136.4	139.2	151.7
507	160–$\frac{40}{60}$–F	——	——	——	——		157.2	159.0	153.2	155.7
508	160–$\frac{50}{70}$–F	199.3	198.1	——	36.8		150.5	154.6	150.7	151.6
510	240–$\frac{25}{45}$–F	214.4	215.2	——	31.9		133.1	137.9	143.5	141.5
511	240–$\frac{30}{55}$–F	224.1	——	28.1	——		140.1	130.8	142.2	130.6
512	240–$\frac{35}{60}$–F	217.9	——	26.4	——		147.1	132.1	141.9	134.6
513	280–$\frac{30}{55}$–F	214.5	——	28.3	——		151.0	137.0	134.0	123.4

Test Number	Laboratory Designation	Pressures from Indicator Cards: Pressures at Cut-off, Pounds Per Square Inch: Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Pressures at Release, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
501	80–$\frac{25}{45}$–F	17.2	17.7	16.6	——	85.1	——	78.9	77.6	8.7	8.3	7.9	——
502	80–$\frac{35}{60}$–F	25.7	25.3	25.1	26.0	102.8	——	100.4	96.4	15.7	15.0	15.5	16.2
505	160–$\frac{25}{45}$–F	14.1	13.1	——	——	81.3	51.6	76.5	71.6	7.9	7.9	——	——
506	160–$\frac{25}{45}$–F	13.5	12.5	13.5	14.0	80.9	52.9	74.9	72.2	7.5	7.7	7.5	7.7
507	160–$\frac{40}{60}$–F	20.9	21.3	20.4	22.0	80.7	79.3	80.7	80.3	12.0	11.9	12.5	12.1
508	160–$\frac{50}{70}$–F	24.6	25.1	25.3	25.6	101.5	96.8	99.9	94.5	18.1	18.2	18.8	18.4
510	240–$\frac{25}{45}$–F	14.1	16.5	15.3	15.2	65.4	62.0	66.8	68.5	7.5	8.0	7.9	7.7
511	240–$\frac{30}{55}$–F	15.2	15.3	15.3	15.6	64.0	59.8	65.2	58.8	8.9	8.7	9.2	7.5
512	240–$\frac{35}{60}$–F	16.2	16.9	16.8	15.5	68.8	65.1	68.7	64.7	9.7	9.6	10.1	10.5
513	280–$\frac{30}{55}$–F	14.3	14.4	15.1	14.9	63.6	55.8	62.0	55.7	8.2	8.5	9.1	9.1

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

Pennsylvania Railroad Company.

Test Number	Laboratory Designation	Pressures from Indicator Cards: Pressures at Beginning of Compression, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Crank End	Left Side: Head End	Crank End	Low Pressure Cylinder: Right Side: Head End	Crank End	Left Side: Head End	Crank End	Least Back Pressure, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Crank End	Left Side: Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
501	80-25/45-F	33.4	—	30.4	35.2	1.7	1.7	1.5	—	29.1	—	26.9	31.5
502	80-35/60-F	39.5	—	38.5	39.6	2.1	1.6	1.5	1.8	36.1	—	35.7	37.5
505	160-25/45-F	35.5	30.1	32.7	33.3	3.4	3.8	—	—	29.7	28.1	28.6	27.4
506	160-25/50-F	36.8	30.2	33.0	35.2	3.3	3.4	3.6	3.2	30.4	26.8	26.8	29.1
507	160-40/60-F	40.3	36.4	42.1	37.3	4.8	4.6	5.2	4.1	34.4	34.1	35.6	32.9
508	160-50/70-F	43.5	38.7	42.6	37.7	7.7	8.2	6.6	7.4	37.7	37.7	38.8	34.7
510	240-25/45-F	44.0	41.1	41.3	43.2	6.4	5.8	6.0	6.0	36.8	36.0	36.1	37.5
511	240-30/50-F	41.0	36.6	38.9	36.3	8.1	8.1	8.5	7.9	29.5	28.8	31.5	28.5
512	240-35/60-F	40.0	36.0	39.2	36.9	9.9	9.6	10.0	9.4	30.2	30.3	30.2	29.6
513	280-30/55-F	42.0	38.2	41.4	37.0	10.3	9.6	10.3	9.7	30.0	29.7	30.0	29.7

Test Number	Laboratory Designation	Pressures from Indicator Cards: Least Back Pressure, Pounds Per Square Inch: Low Pressure Cylinder: Right Side: Head End	Crank End	Left Side: Head End	Crank End	Boiler: Dry Coal Fired Pounds: Per Hour	Per Hour Per Square Foot of Grate Surface	Evaporation, Pounds: Steam Per Hour: Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
501	80-25/45-F	.4	1.0	.4	—	690	20.67	7066	6990	2.632	10.130
502	80-35/60-F	1.0	1.1	.8	.8	1005	30.09	9742	9634	3.627	9.589
505	160-25/45-F	1.7	2.2	—	—	1157	34.66	11007	10889	4.099	9.410
506	160-25/50-F	1.3	1.9	1.0	1.6	1259	37.71	11646	11514	4.335	9.144
507	160-40/60-F	2.8	2.9	2.9	2.8	2247	67.31	16599	16382	6.167	7.290
508	160-50/70-F	6.1	6.6	5.9	6.3	3038	91.00	20184	19977	7.521	6.575
510	240-25/45-F	2.0	2.0	2.0	2.0	1761	52.74	13662	13508	5.085	7.671
511	240-30/50-F	3.9	3.7	4.0	3.3	2395	71.74	15636	15430	5.809	6.442
512	240-35/60-F	5.0	4.2	4.8	4.6	2641	79.09	18241	18003	6.778	6.818
513	280-30/55-F	4.0	3.1	3.9	3.9	2897	86.77	19373	19115	7.196	6.598

For steam lost from boiler and not delivered to engines, see item 216.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Per Hour, Per Sq. Ft. of Heat. Surface	Per Pound of: Coal as Fired	Dry Coal as Fired	Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		344	345	346	347	348	349	350	351	352	353	354
501	80-25/45-F	8416	3.17	12.08	12.19	13.01	244.0	78.55	66.29	56.70	66.08	56.62
502	80-35/60-F	11580	4.36	11.43	11.53	12.40	335.7	74.88	94.57	90.11	95.00	90.52
505	160-25/45-F	13089	4.93	11.19	11.31	12.08	379.4	73.29	64.51	34.46	62.75	58.30
506	160-25/45-F	13810	5.20	10.87	10.97	11.58	400.3	70.68	65.29	35.46	63.45	55.92
507	160-40/60-F	20091	7.56	8.86	8.94	9.42	582.4	56.87	81.12	78.98	79.75	82.63
508	160-50/70-F	23999	9.04	7.82	7.90	8.40	695.6	51.35	92.13	93.30	96.53	93.21
510	240-25/45-F	16273	6.13	9.14	9.24	9.92	471.7	59.93	40.49	40.06	46.42	41.01
511	240-30/55-F	18933	7.13	7.83	7.90	8.49	548.8	51.35	50.37	44.47	53.40	46.61
512	240-35/60-F	22088	8.32	8.29	8.36	9.19	640.3	55.99	61.96	58.80	64.18	60.16
513	280-30/55-F	23453	8.83	8.02	8.10	8.58	679.8	51.48	49.90	42.39	48.92	45.22

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square Inch: Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Receiver Pressure: Right Side	Receiver Pressure: Left Side	Number of Expansions: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		355	356	357	358	359	360	361	362	363	364
501	80-25/45-F	13.46	13.09	13.16	12.80			5.56	6.14	6.01	6.38
502	80-35/60-F	22.95	22.54	22.80	23.40			4.72	4.94	5.01	5.28
505	160-25/45-F	9.79	10.11	9.79	10.11			5.15	3.59	5.46	6.28
506	160-25/45-F	9.90	9.87	9.84	10.11			4.86	3.47	5.13	6.02
507	160-40/60-F	16.37	17.03	17.02	17.35			5.14	5.44	4.86	5.20
508	160-50/70-F	19.50	20.08	20.03	19.91			4.20	4.57	4.06	4.39
510	240-25/45-F	7.04	7.31	7.95	7.63			5.44	6.00	5.51	6.13
511	240-30/55-F	6.50	7.20	7.37	7.72			5.52	5.97	5.45	5.78
512	240-35/60-F	7.73	8.24	8.59	8.81			5.57	5.68	5.23	5.62
513	280-30/55-F	4.22	5.35	5.72	6.25			5.97	6.26	5.29	5.47

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
501	80-$\frac{25}{45}$-F	53.3	43.9	53.1	43.8	29.9	29.0	29.2	28.3	97.2	96.9	58.8	57.6
502	80-$\frac{35}{60}$-F	76.0	69.9	76.4	70.2	50.9	49.9	50.7	51.8	145.9	146.5	100.8	102.5
505	160-$\frac{25}{45}$-F	103.7	53.4	100.8	90.3	43.4	44.7	43.5	44.8	157.0	191.1	88.1	88.2
506	160-$\frac{25}{45}$-F	104.9	55.0	101.9	86.7	43.9	43.7	43.7	44.8	159.9	188.6	87.6	88.5
507	160-$\frac{40}{60}$-F	130.4	122.4	128.1	128.0	72.6	75.3	75.6	76.8	252.8	256.2	147.9	152.4
508	160-$\frac{50}{70}$-F	148.1	144.6	155.1	144.4	86.5	88.8	89.0	88.2	292.6	299.5	175.3	177.1
510	240-$\frac{25}{45}$-F	97.6	93.1	111.9	95.3	46.9	48.5	52.9	50.7	190.7	207.2	95.4	103.6
511	240-$\frac{30}{55}$-F	121.4	103.4	128.7	108.3	43.3	47.8	49.1	51.3	224.8	237.1	91.0	100.4
512	240-$\frac{35}{60}$-F	149.4	136.7	154.7	139.8	51.4	54.7	57.2	58.5	286.0	294.5	106.1	115.7
513	280-$\frac{30}{55}$-F	140.3	115.0	137.5	122.6	32.8	41.4	44.5	48.4	255.3	260.2	74.2	92.9

Test Number	Laboratory Designation	Engines						Locomotive			
		Division of Power			Consumed Per I. H. P., Hour			Dynamometer Horse Power	Pounds Per D. H. P., Hour		B. T. U. Per D. H. P., Hour
		Total									
		Right Side	Left Side	Total I. H. P.	Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.		Of Dry Coal	Of Dry Steam	
		377	378	379	380	381	382	383	384	385	386
501	80-$\frac{25}{45}$-F	156.0	154.4	310.4	2.09	21.20	31360	277.7	2.34	23.70	35057
502	80-$\frac{35}{60}$-F	246.7	249.0	495.7	1.94	18.60	28824	439.7	2.19	20.96	32492
505	160-$\frac{25}{45}$-F	245.2	279.3	524.5	2.12	19.95	31610	443.0	2.52	23.77	37641
506	160-$\frac{25}{45}$-F	247.4	277.1	524.5	2.31	21.15	34644	453.8	2.67	24.45	40051
507	160-$\frac{40}{60}$-F	400.7	408.6	809.3	2.69	19.60	40807	609.7	3.57	26.01	54155
508	160-$\frac{50}{70}$-F	467.9	476.6	944.6	3.14	20.67	46694	842.9	3.52	23.16	52326
510	240-$\frac{25}{45}$-F	286.1	310.8	596.8	2.86	21.95	42583	353.4	4.83	37.06	71907
511	240-$\frac{30}{55}$-F	315.8	337.4	653.2	3.52	22.69	52328	560.7	4.10	26.42	60954
512	240-$\frac{35}{60}$-F	392.1	410.2	802.3	3.17	21.62	45733	653.1	3.90	26.56	56178
513	280-$\frac{30}{55}$-F	329.5	358.0	682.5	4.10	27.05	62239	510.1	5.48	36.19	83263

For Maximum Indicated Horse Power, see item 403.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

PENNSYLVANIA RAILROAD COMPANY.

Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Per One Million Foot Pounds at Draw-Bar: Dry Steam, Pounds	Per One Million Foot Pounds at Draw-Bar: B. T. U.	I. H. P. Per Square Foot of: Heating Surface	I. H. P. Per Square Foot of: Grate Surface	D. H. P. Per Square Foot of: Heating Surface	D. H. P. Per Square Foot of: Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	Machine Friction of Locomotive, in Terms of: M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
501	80-25/45-F	1.16	11.75	17389	.1169	9.30	.1045	8.32	6086	32.76		642
502	80-35/60-F	1.10	10.59	16409	.1866	14.84	.1655	13.17	9718	55.95		1096
505	160-25/45-F	1.41	13.25	20991	.1974	15.71	.1667	13.27	5142	81.49		799
506	160-25/45-F	1.35	12.35	20228	.1974	15.71	.1708	13.59	5142	70.70		693
507	160-40/60-F	1.80	13.14	27349	.3046	24.23	.2634	20.95	7983	199.58		1956
508	160-50/70-F	1.78	11.70	26423	.3556	28.29	.3173	25.24	9259	101.67		997
510	240-25/45-F	2.44	18.72	36320	.2247	17.88	.1331	10.58	3901	243.42		1591
511	240-30/55-F	2.07	13.35	30783	.2459	19.56	.2111	16.79	4269	92.47		604
512	240-35/60-F	1.97	13.42	28374	.3020	24.03	.2458	19.56	5244	149.25		976
518	280-40/55-F	2.42	16.00	36805	.2569	20.44	.1920	15.28	3823	172.38		966

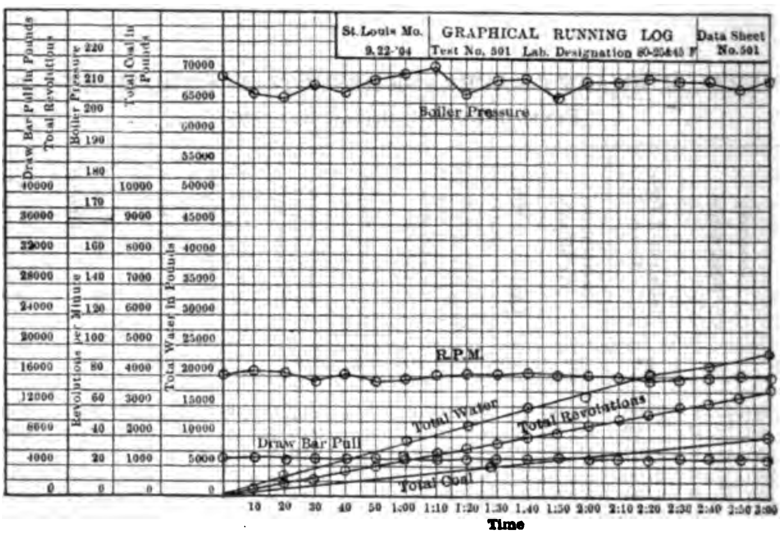
Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Locomotive: Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Ratios: Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
501	80-25/45-F	89.45	7.26	516.1	8.36	550	317.9				9-23-04
502	80-35/60-F	88.71	7.83	321.0	5.20	871	510.9				9-24-04
505	160-25/45-F	84.46	6.76	299.4	4.85	790	547.9				9-26-04
506	160-25/45-F	86.52	6.35	299.4	4.85	899	547.8				9-27-04
507	160-40/60-F	75.35	4.70	193.7	3.14	1207	846.3				11-26-04
508	160-50/70-F	89.23	4.86	159.6	2.59	1669	1027.3				10-3-04
510	240-25/45-F	59.22	3.54	269.8	4.37	700	607.9				10-7-04
511	240-30/55-F	85.85	4.18	238.9	3.87	1110	686.4				11-29-04
512	240-35/60-F	81.41	4.53	198.2	3.21	1293	827.3				11-29-04
513	280-40/55-F	74.74	3.06	231.4	3.75	1154	708.6				11-29-04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 2512.

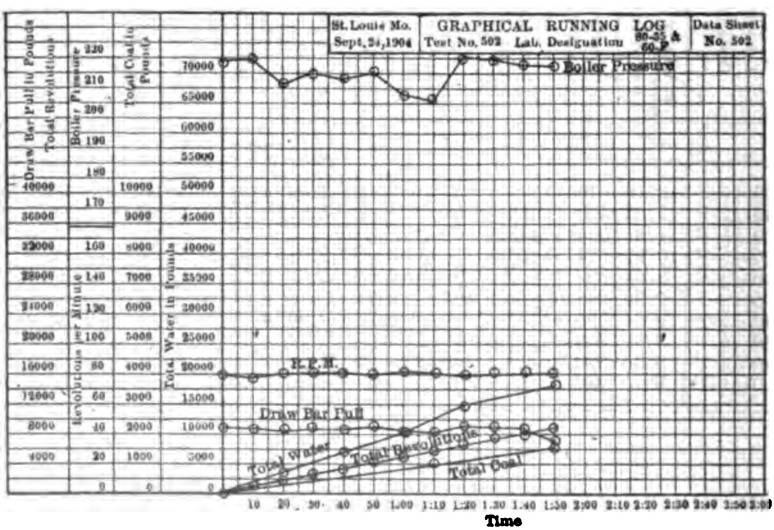
Pennsylvania Railroad Company.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft in Smokebox, Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	208	217	220	222	338	341
501	80-$\frac{25}{45}$-F	3.00	80.00	19.13	26.9	Full	212.0	208.7	.33	690	6990
502	80-$\frac{35}{60}$-F	1.83	80.05	19.14	39.1	"	215.2	210.8	.92	1005	9634
505	160-$\frac{25}{45}$-F	1.67	159.96	38.25	25.2	"	219.7	215.2	1.40	1157	10889
506	160-$\frac{25}{45}$-F	3.00	160.00	38.26	27.3	"	219.6	214.7	.84	1259	11514
507	160-$\frac{40}{60}$-F	3.00	160.00	38.26	38.4	"	214.6	206.2	2.42	2247	16382
508	160-$\frac{50}{70}$-F	3.00	160.00	38.26	49.7	"	206.4	200.4	3.53	3038	19977
510	240-$\frac{25}{45}$-F	2.00	240.00	57.39	27.7	"	212.5	209.6	1.64	1761	13508
511	240-$\frac{30}{35}$-F	2.00	240.00	57.39	29.8	"	218.9	209.7	3.13	2395	15430
512	240-$\frac{35}{60}$-F	2.00	239.99	57.39	34.2	"	217.5	207.1	3.56	2641	18003
513	280-$\frac{30}{35}$-F	1.24	279.99	66.96	29.2	"	215.0	204.4	3.27	2897	19115

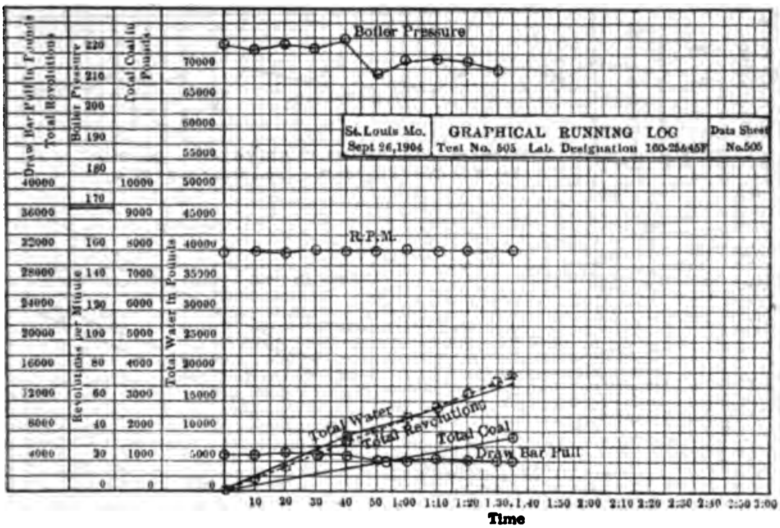
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		347	379	383	395	265	380	384	381	385	350	399
501	80-$\frac{25}{45}$ F	12.19	310.4	277.7	32.76	5443	2.09	2.34	21.20	23.70	78.55	7.26
502	80-$\frac{35}{60}$-F	11.53	495.7	439.7	55.95	8615	1.94	2.19	18.60	20.96	74.88	7.83
505	160-$\frac{25}{45}$-F	11.31	524.5	443.0	81.49	4343	2.12	2.52	19.95	23.77	73.29	6.76
506	160-$\frac{25}{45}$-F	10.97	524.5	453.8	70.70	4448	2.31	2.67	21.15	24.45	70.68	6.35
507	160-$\frac{40}{60}$-F	8.94	809.3	609.7	199.53	5976	2.69	3.57	19.60	26.01	56.87	4.70
508	160-$\frac{50}{70}$-F	7.90	944.6	842.9	101.67	8262	3.14	3.52	20.67	23.16	51.35	4.86
510	240-$\frac{25}{45}$-F	9.24	596.8	353.4	243.42	2309	2.86	4.88	21.95	37.06	59.93	3.54
511	240-$\frac{30}{35}$-F	7.90	653.2	560.7	92.47	3664	3.52	4.10	22.69	26.42	51.35	4.18
512	240-$\frac{35}{60}$-F	8.36	802.3	653.1	149.25	4268	3.17	3.90	21.62	26.56	55.99	4.53
513	280-$\frac{30}{35}$-F	8.10	682.5	510.1	172.38	2857	4.10	5.48	27.05	36.19	51.48	3.06



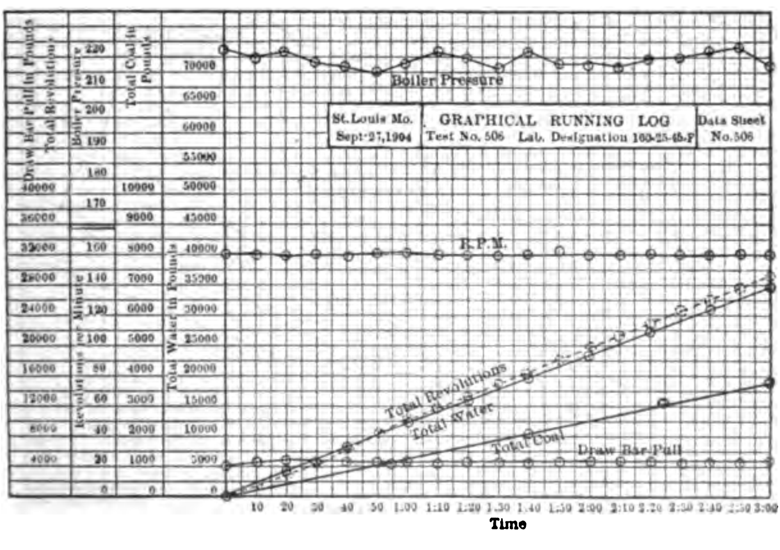
Test No. 501.



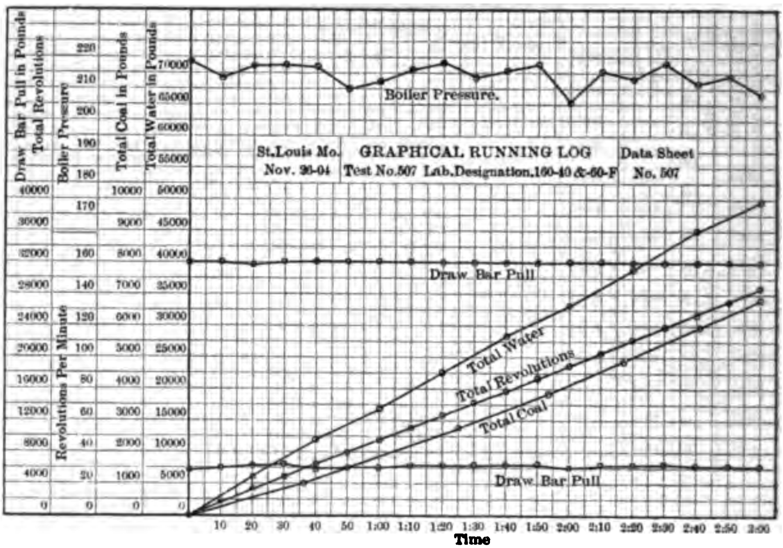
Test No. 502.



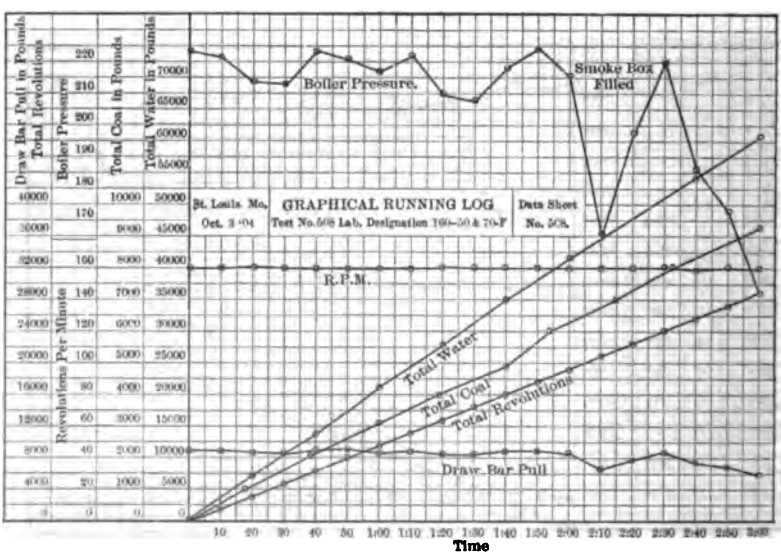
Test No. 505.



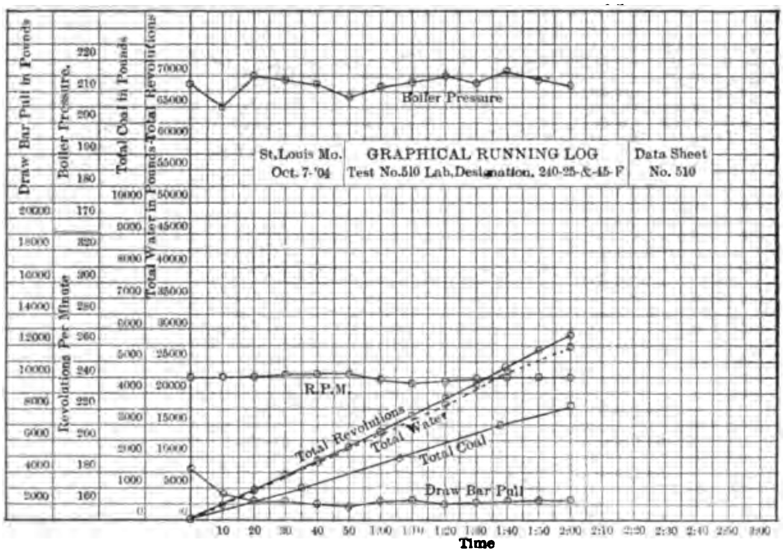
Test No. 506.



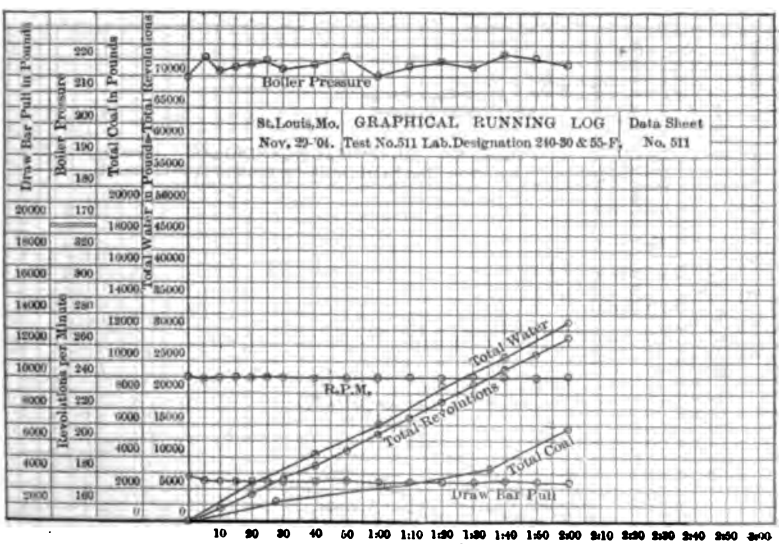
Test No. 507.



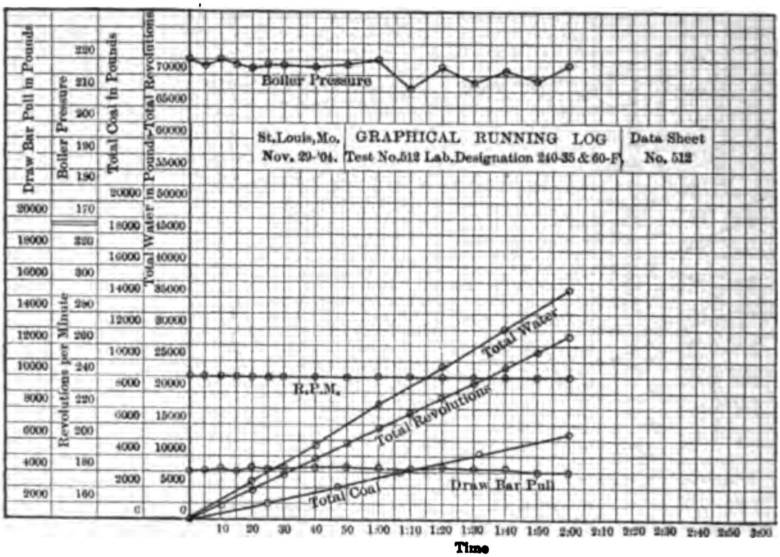
Test No. 508.



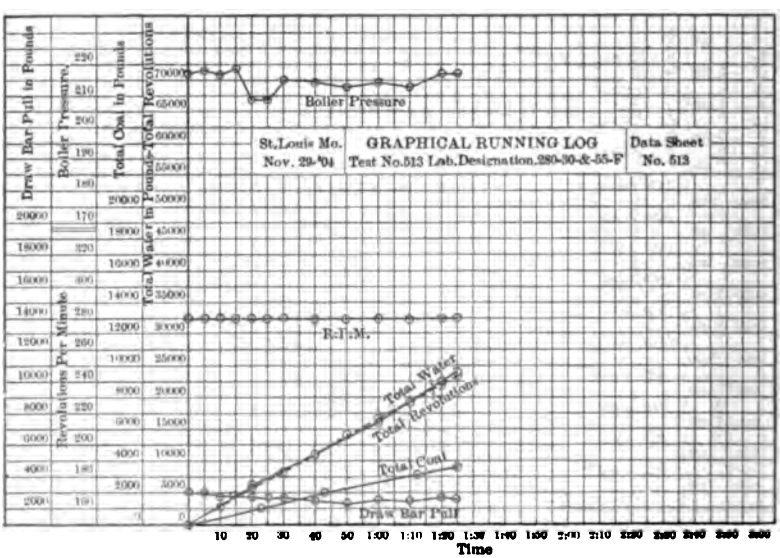
Test No. 510.



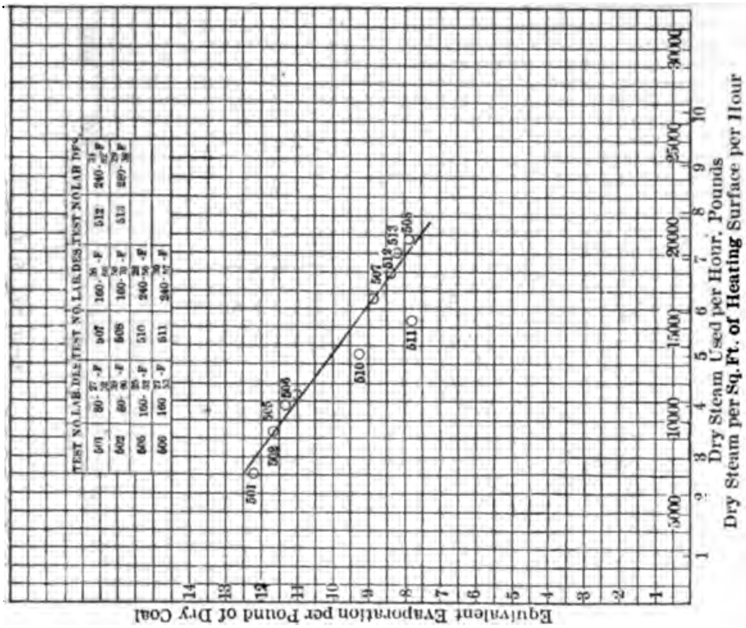
Test No. 511.



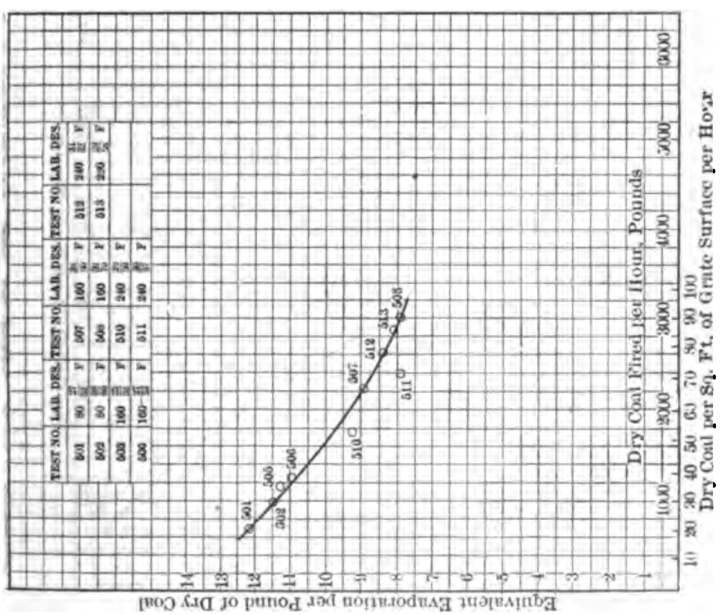
Test No. 512.



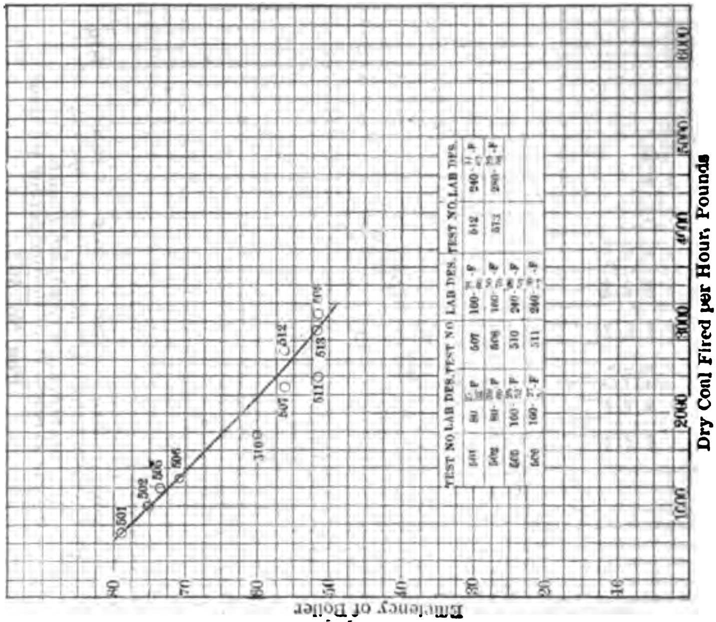
Test No. 513.



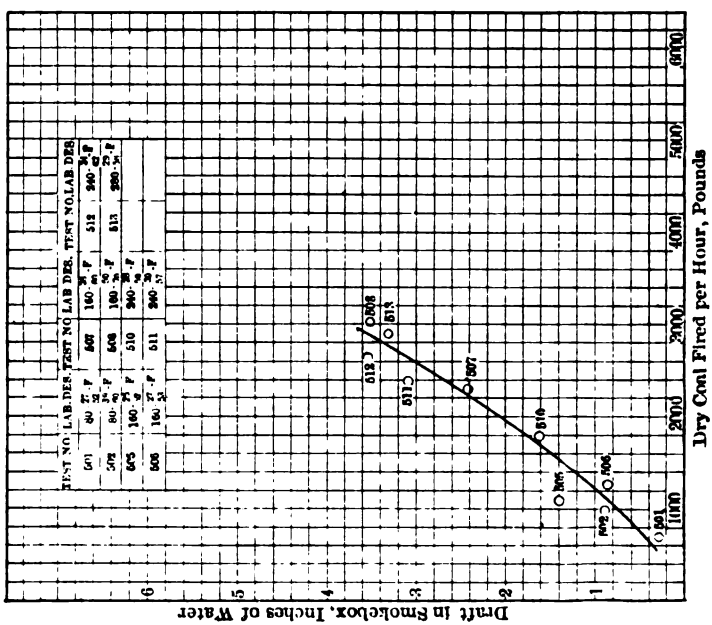
Plot No. 502.



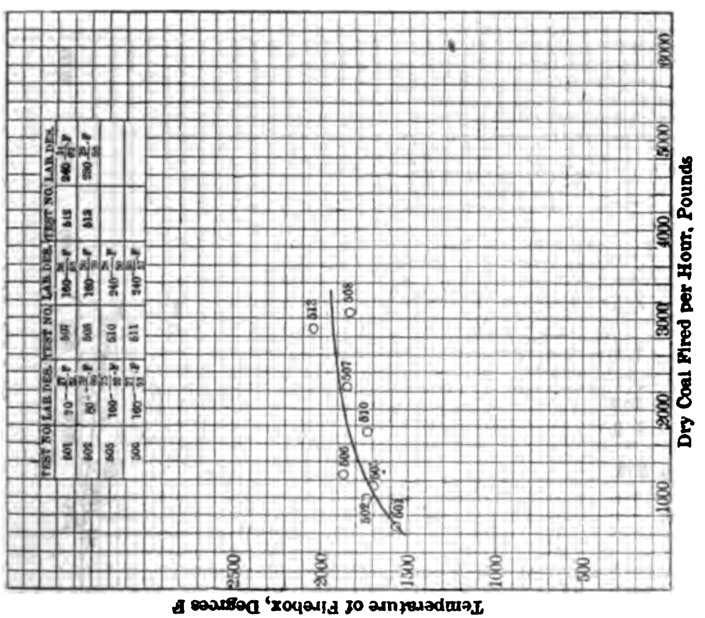
Plot No. 501.



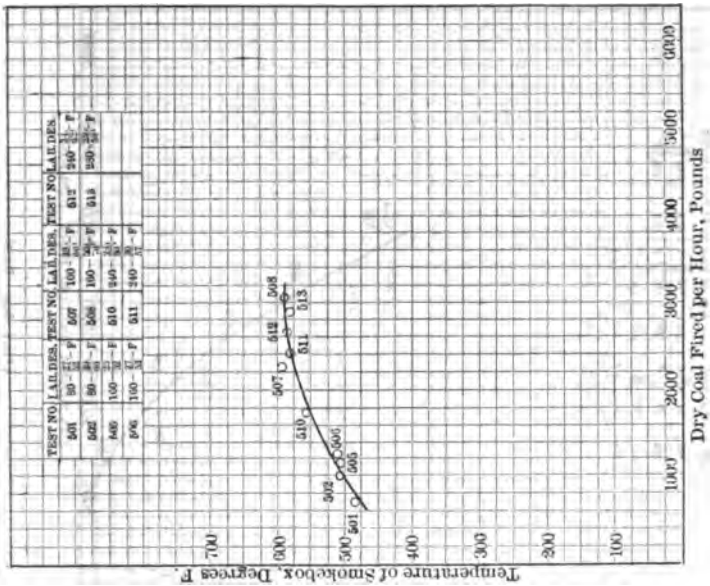
Test No. 504.



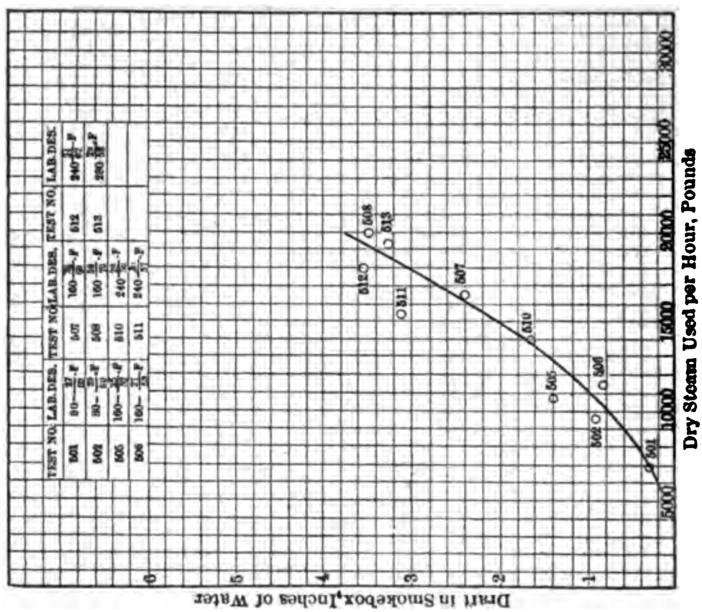
Test No. 503.



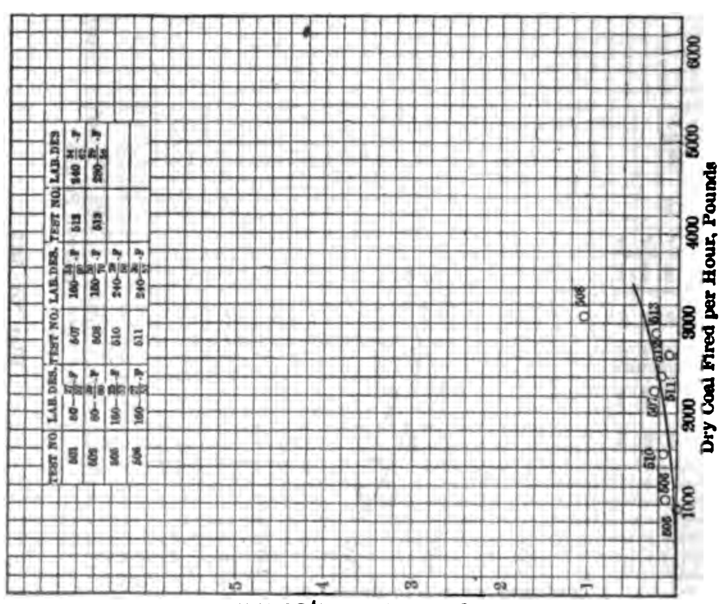
Plot No. 505.



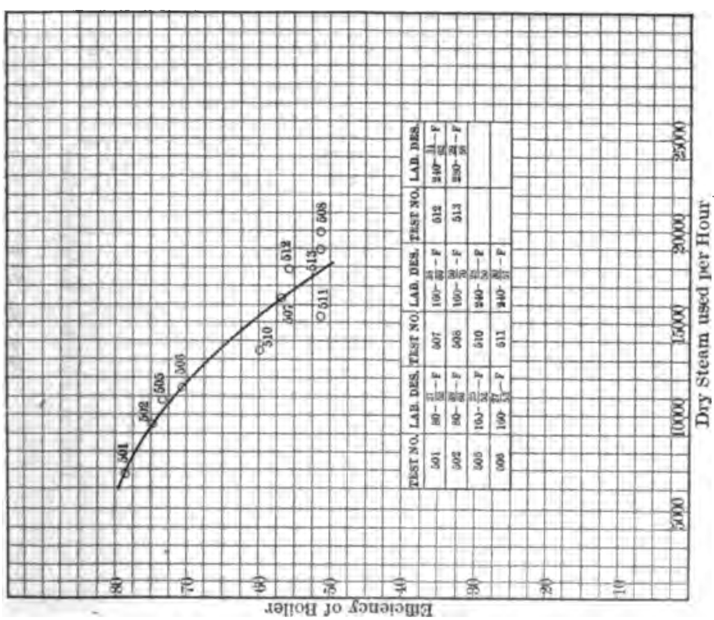
Plot No. 506.



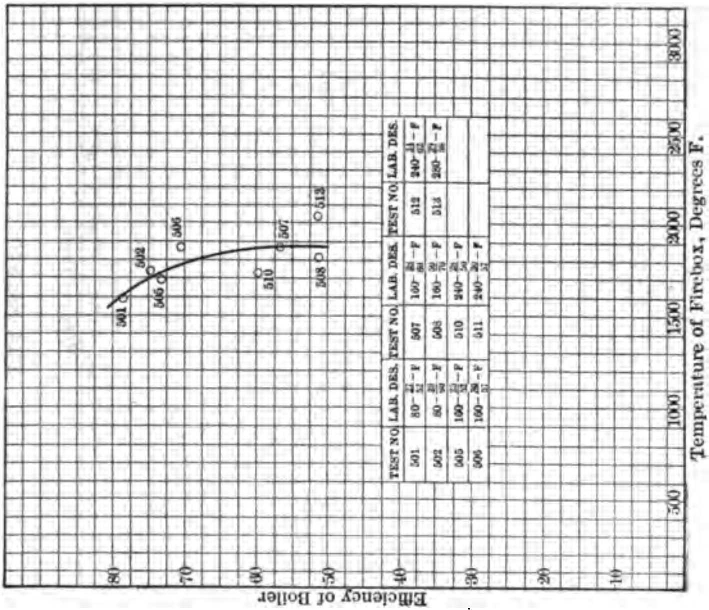
Plot No. 508,



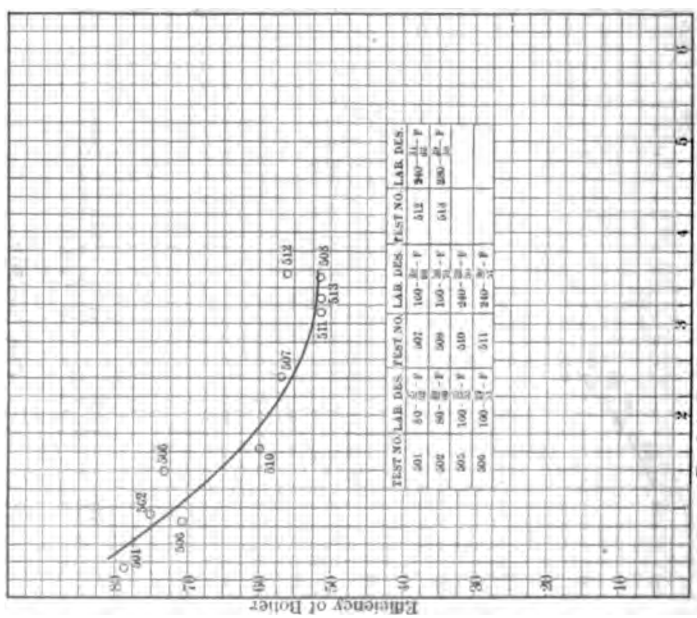
Plot No. 507,



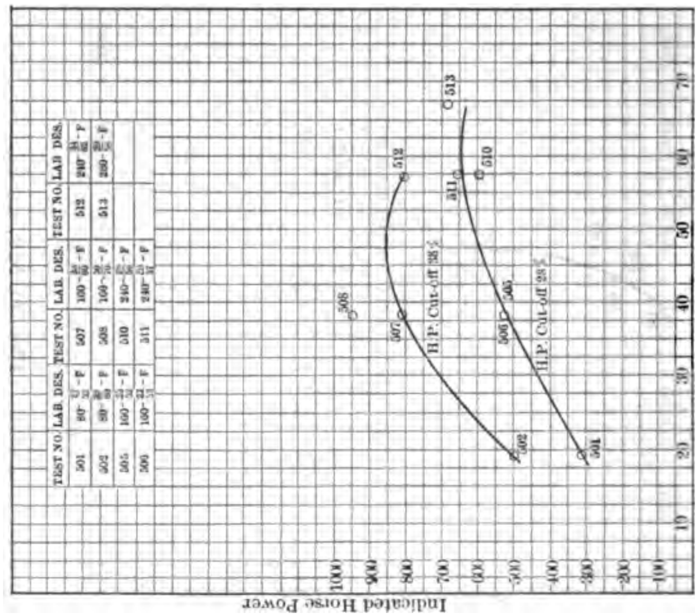
Plot No. 509.



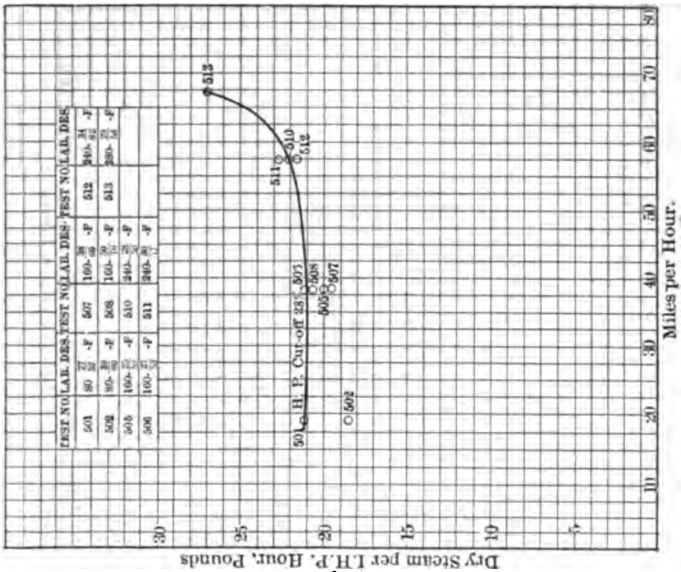
Plot No. 510.



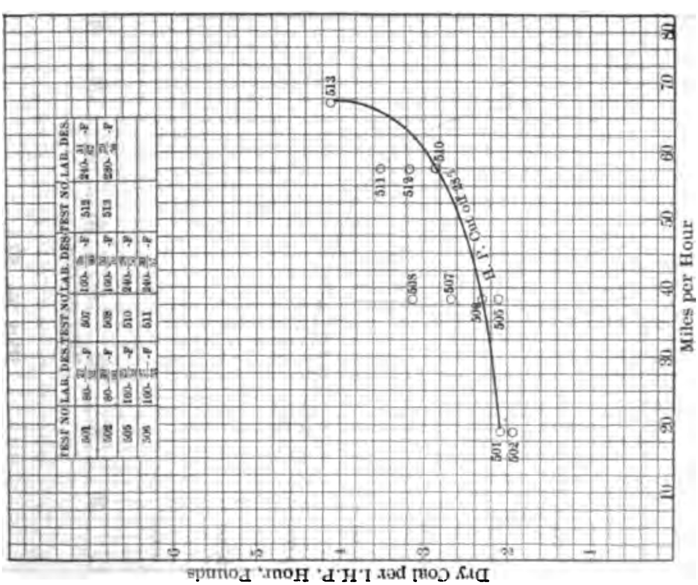
Plot No. 511.



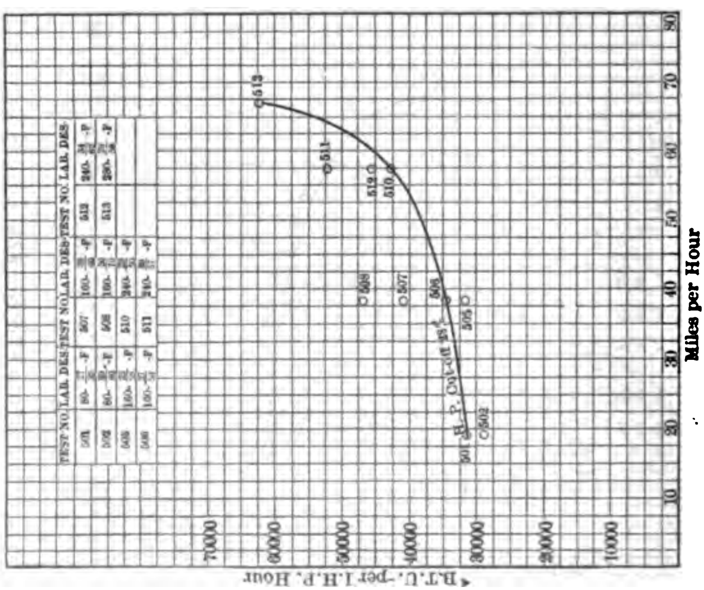
Plot No. 520.



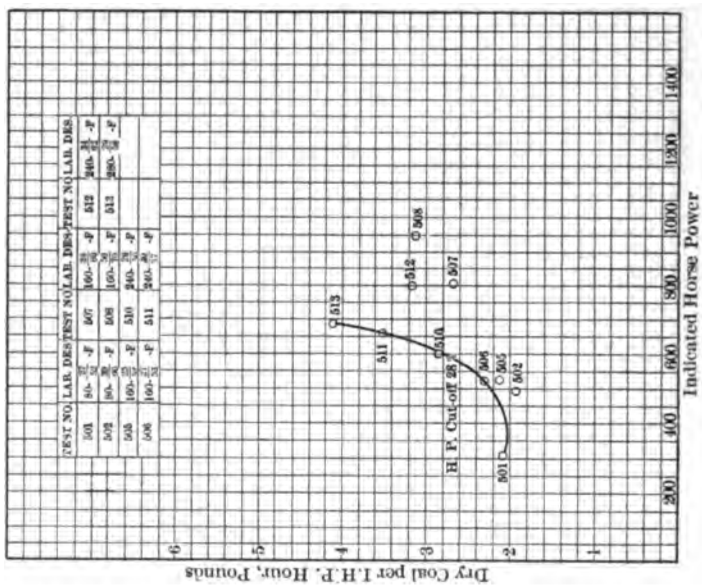
Plot No. 522.



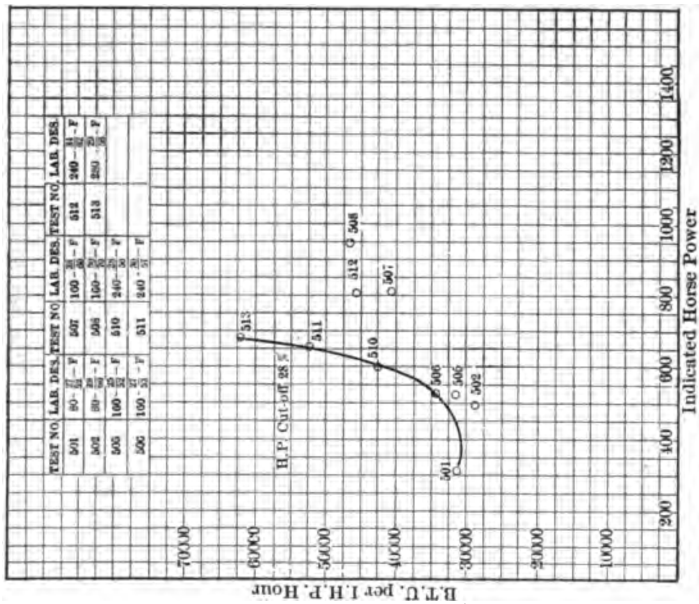
Plot No. 521.



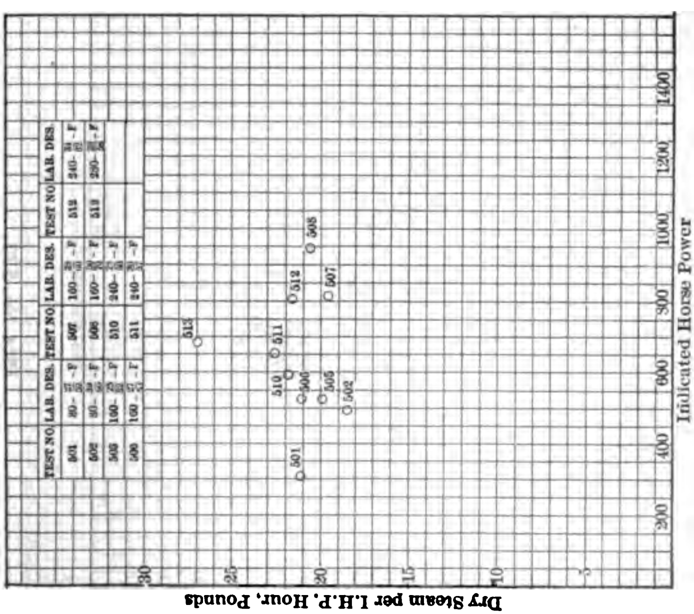
Plot No. 523.



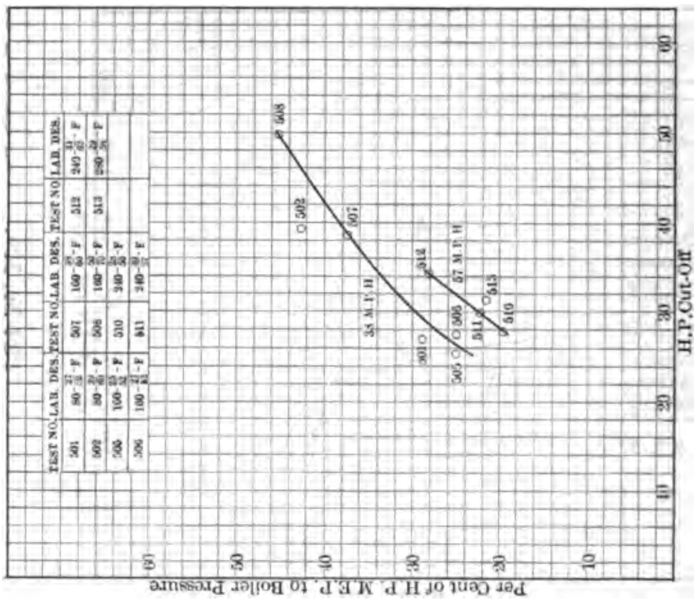
Plot No. 524.



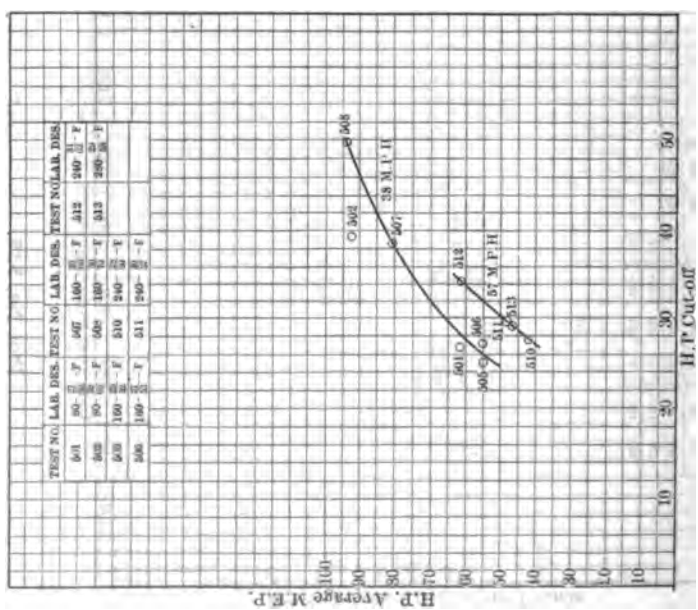
Plot No. 526.



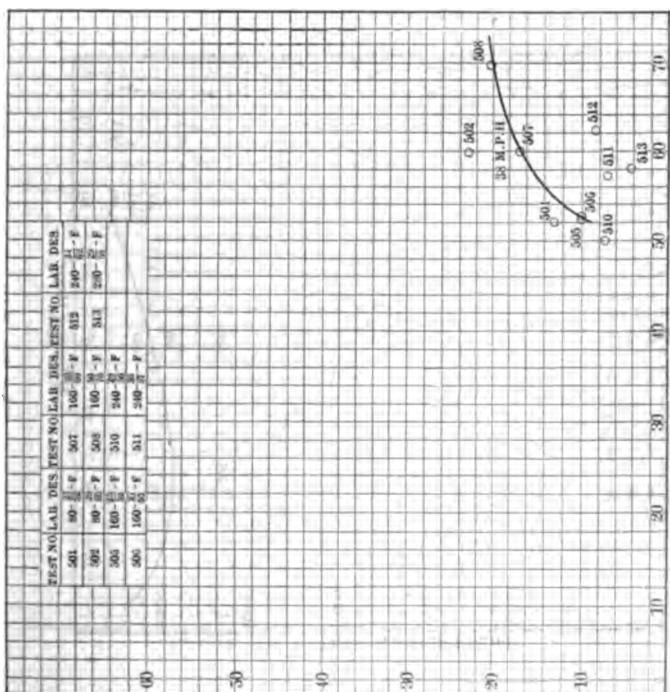
Plot No. 525.



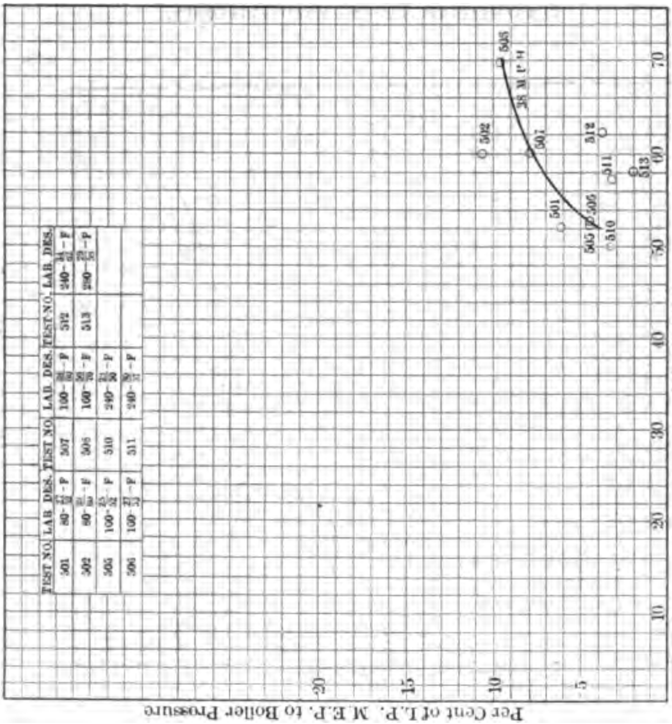
Plot No. 528.



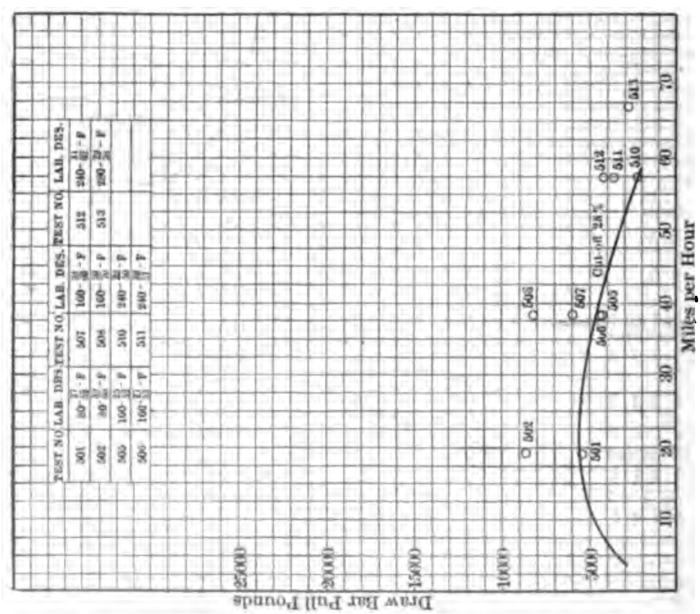
Plot No. 527.



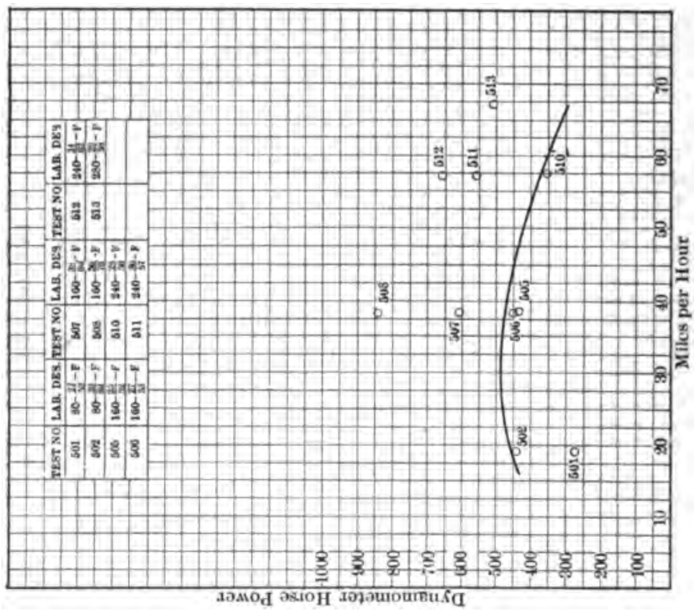
Plot No. 529.



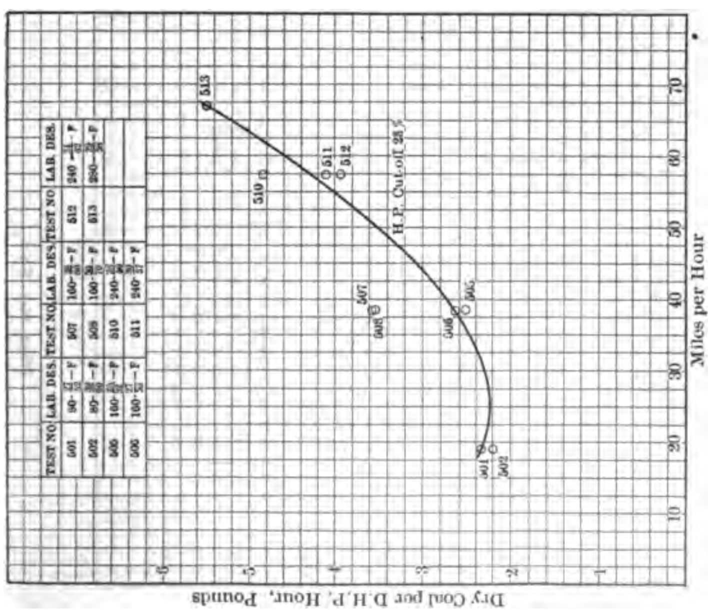
Plot No. 530.



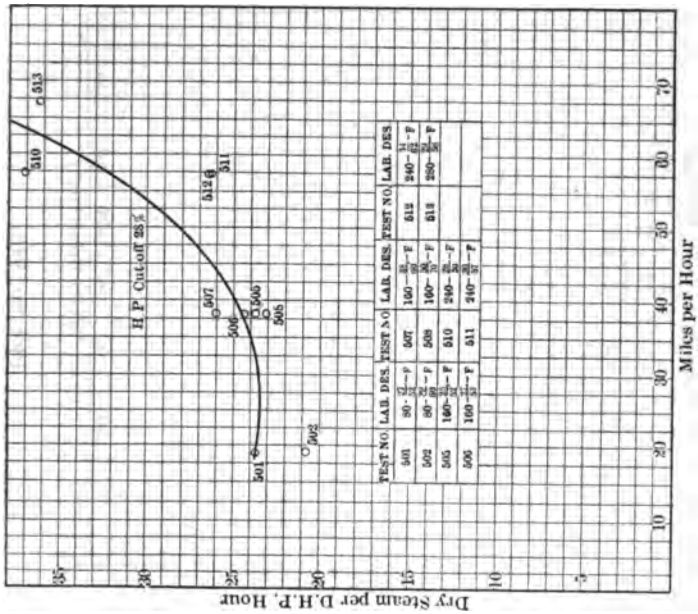
Plot No. 540.



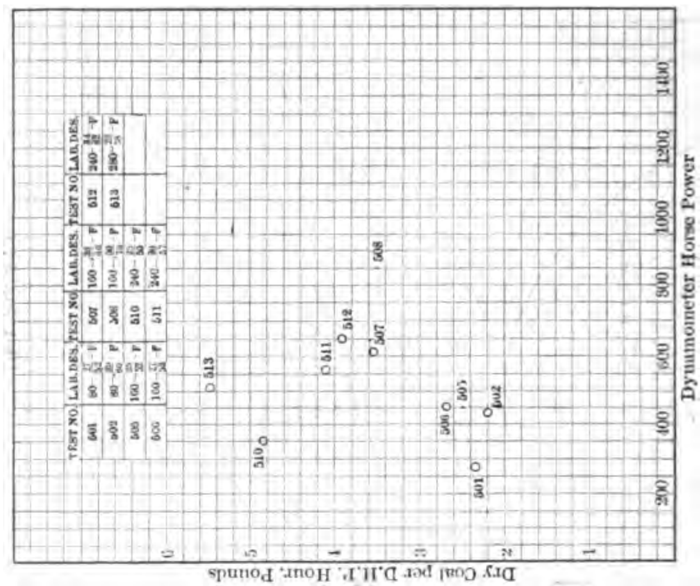
Plot No. 541.



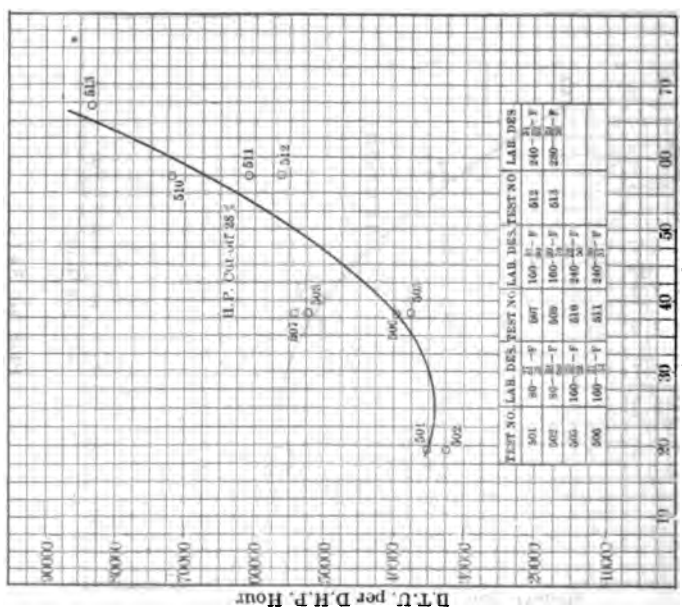
Plot No. 542.



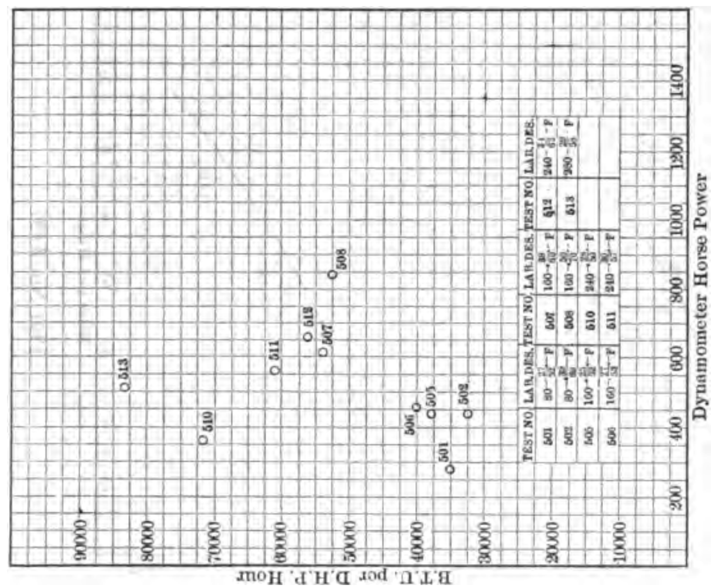
Plot No. 543.



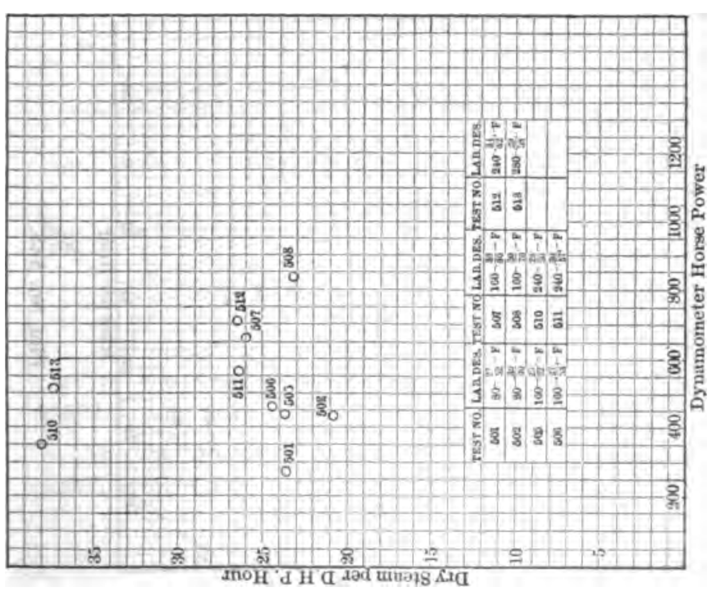
Plot No. 545.



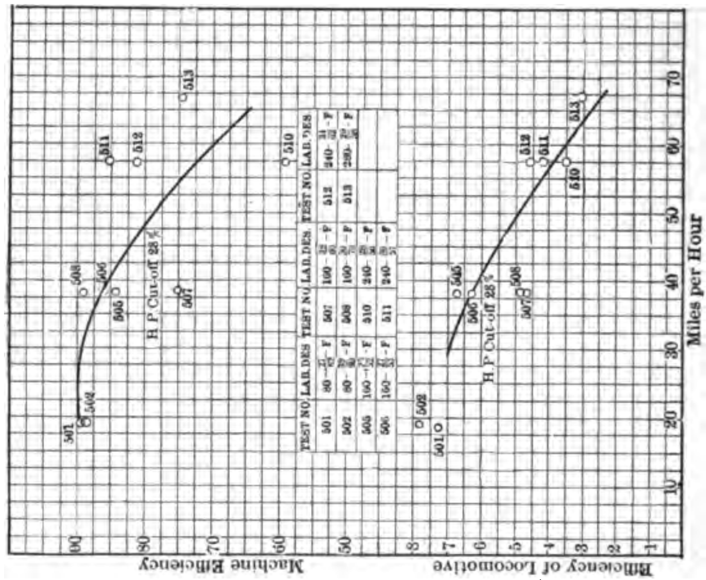
Plot No. 544.



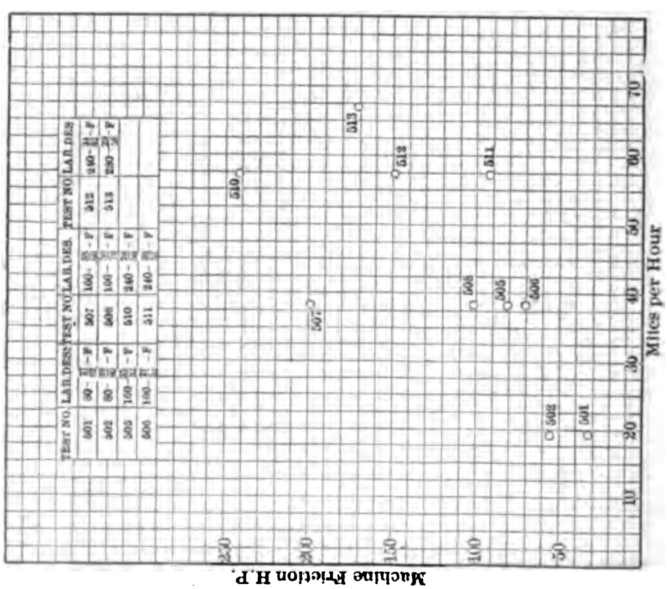
Plot No. 547.



Plot No. 546.



Plot No. 549.

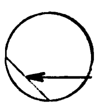
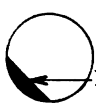


Plot No. 548.

COUNTERBALANCE TESTS

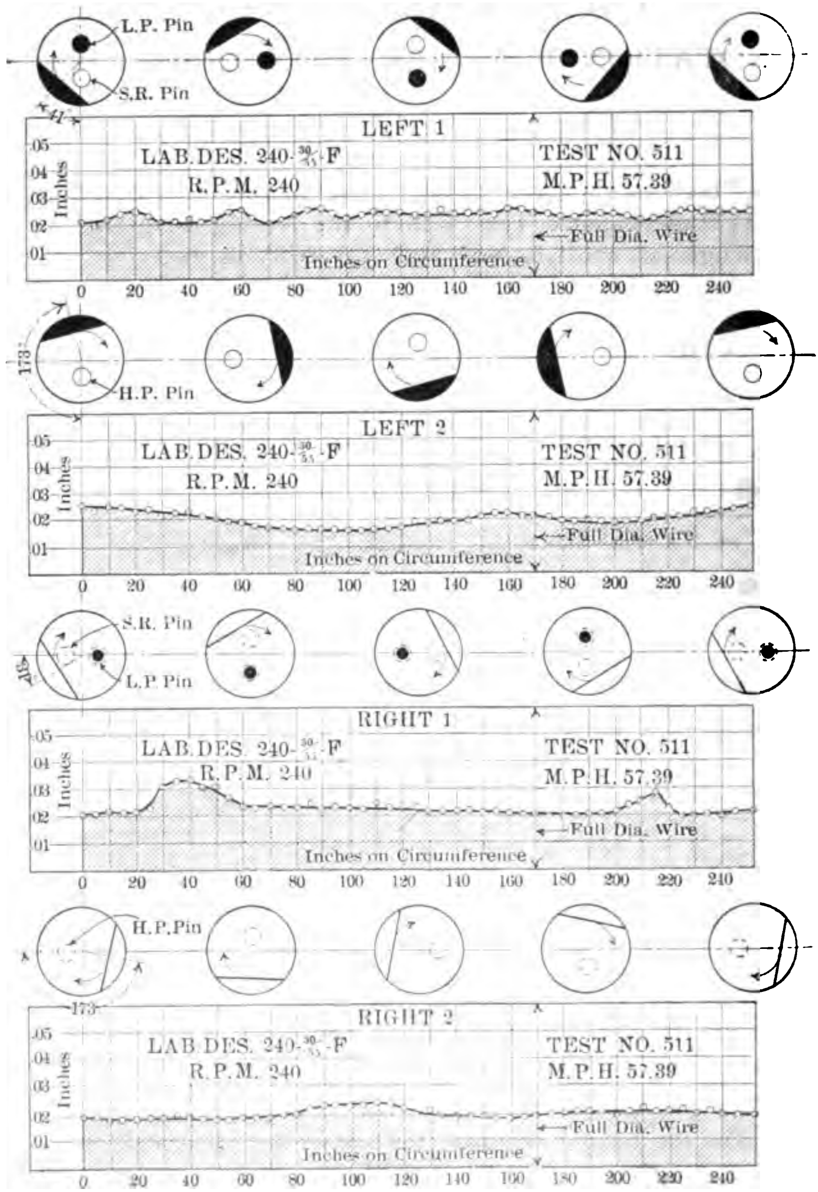
NOTATION FOR VIBRATION DIAGRAMS.

The notation given below applies to the Wire Diagrams for Counterbalance Tests and to the Nosing Diagrams for passenger locomotives Nos. 2512, 535, 628 and 3000.

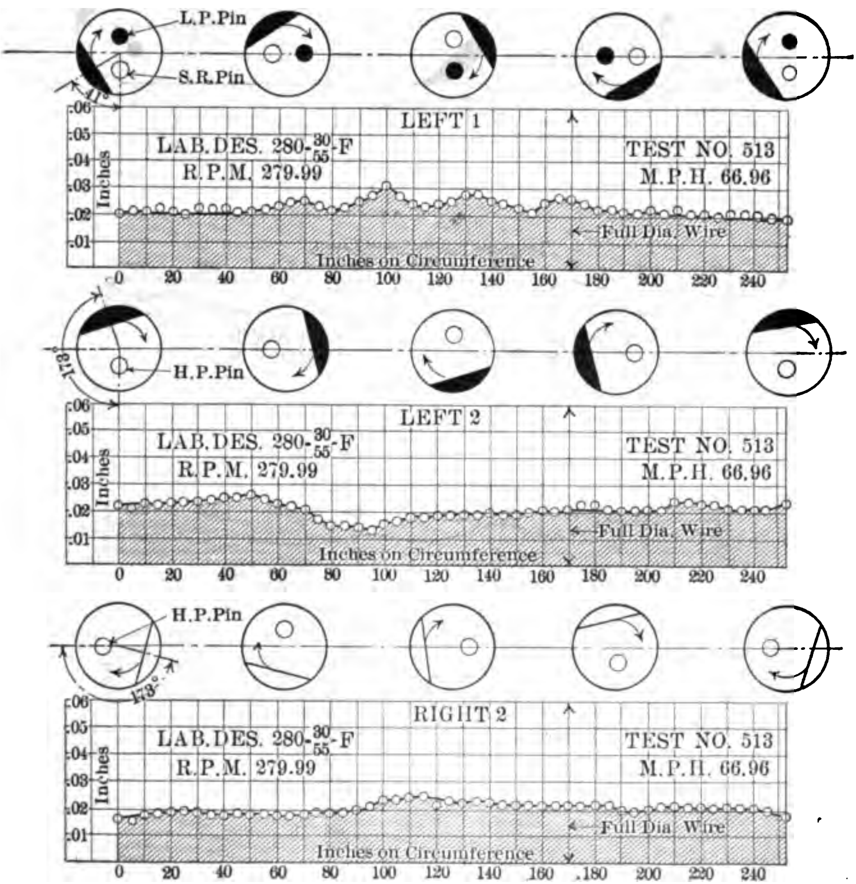
	H.P. Pin—Main crank pin,			High Pressure,		Right driving wheel.		
	L.P. Pin—	"	"	" Low	"	"	"	"
	H.P. Pin—	"	"	" High	"	Left	"	"
	L.P. Pin—	"	"	" Low	"	"	"	"
	S.R. Pin—Side Rod			" High	"	Right	"	"
	S.R. Pin—	"	"	" Low	"	"	"	"
	S.R. Pin—	"	"	" High	"	Left	"	"
	S.R. Pin—	"	"	" Low	"	"	"	"
	R. Weight——Counterbalance Weight in					Right	"	"
	L. Weight——	"			"	Left	"	"

The shaded portion of the wire diagram shows the thickness of the wire after having been run under the driving wheel.

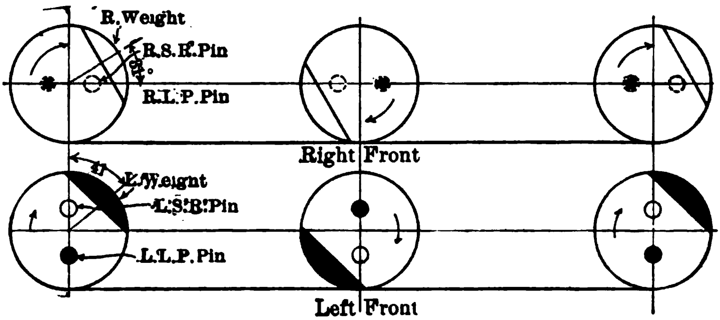
On the nosing diagram the curve is that drawn by the pencil attached to the pilot of the locomotive.

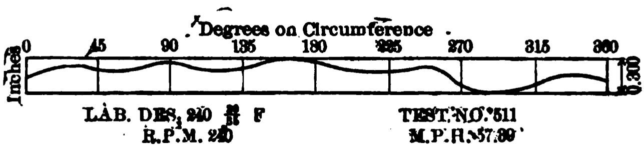


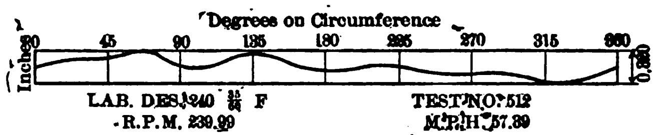
Wire Diagrams for Counterbalance Tests, Locomotive No. 3512.

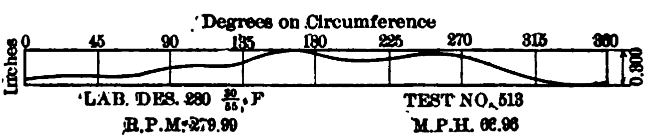


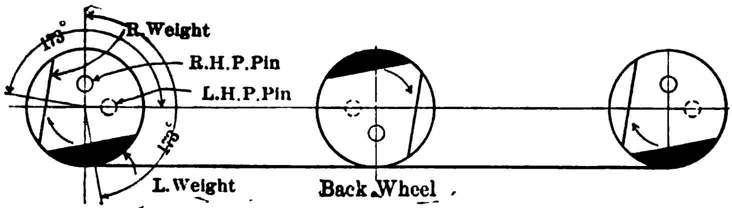
Wire Diagrams for Counterbalance Tests, Locomotive No. 2512.



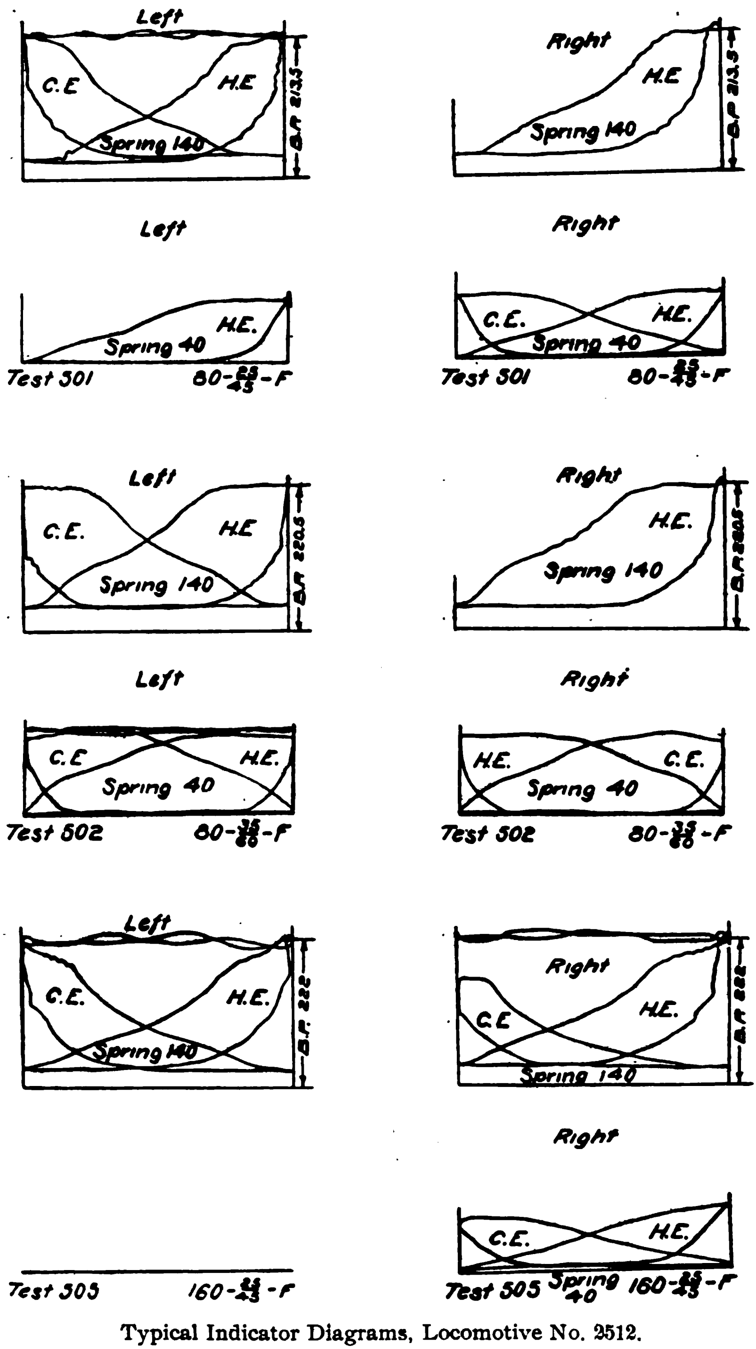




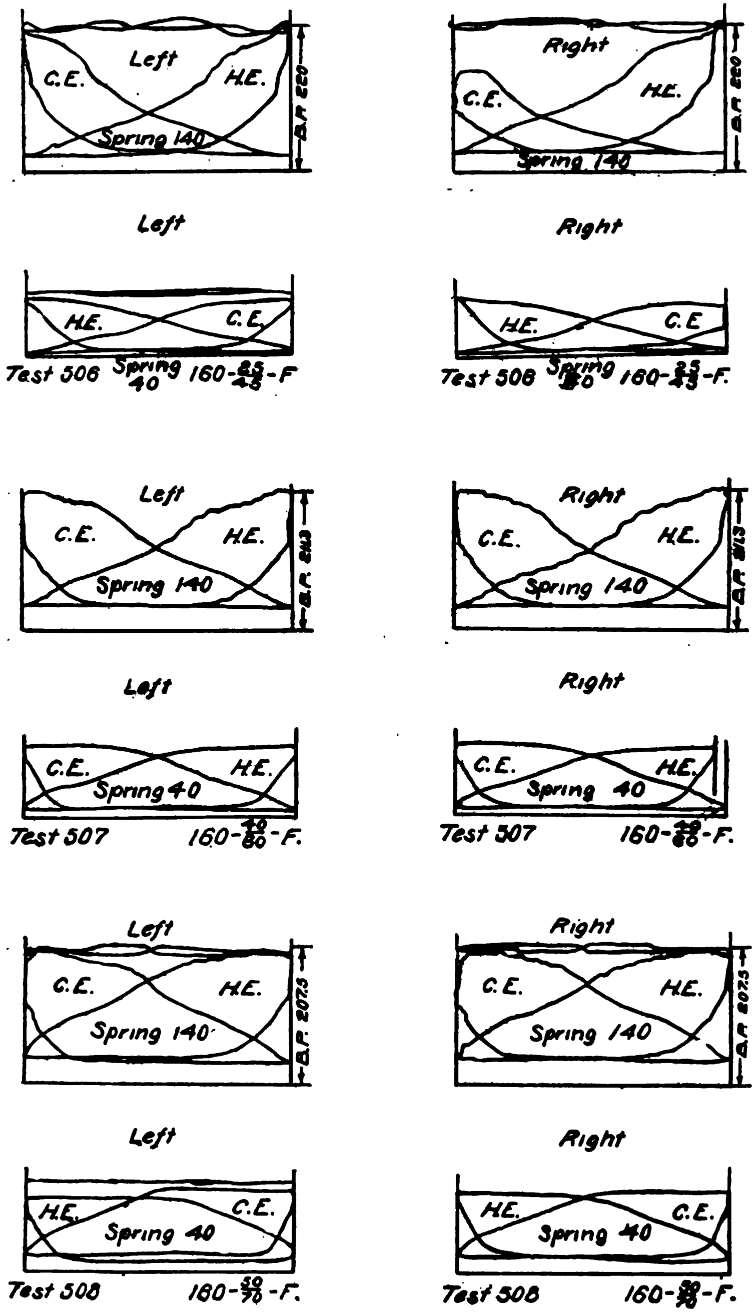




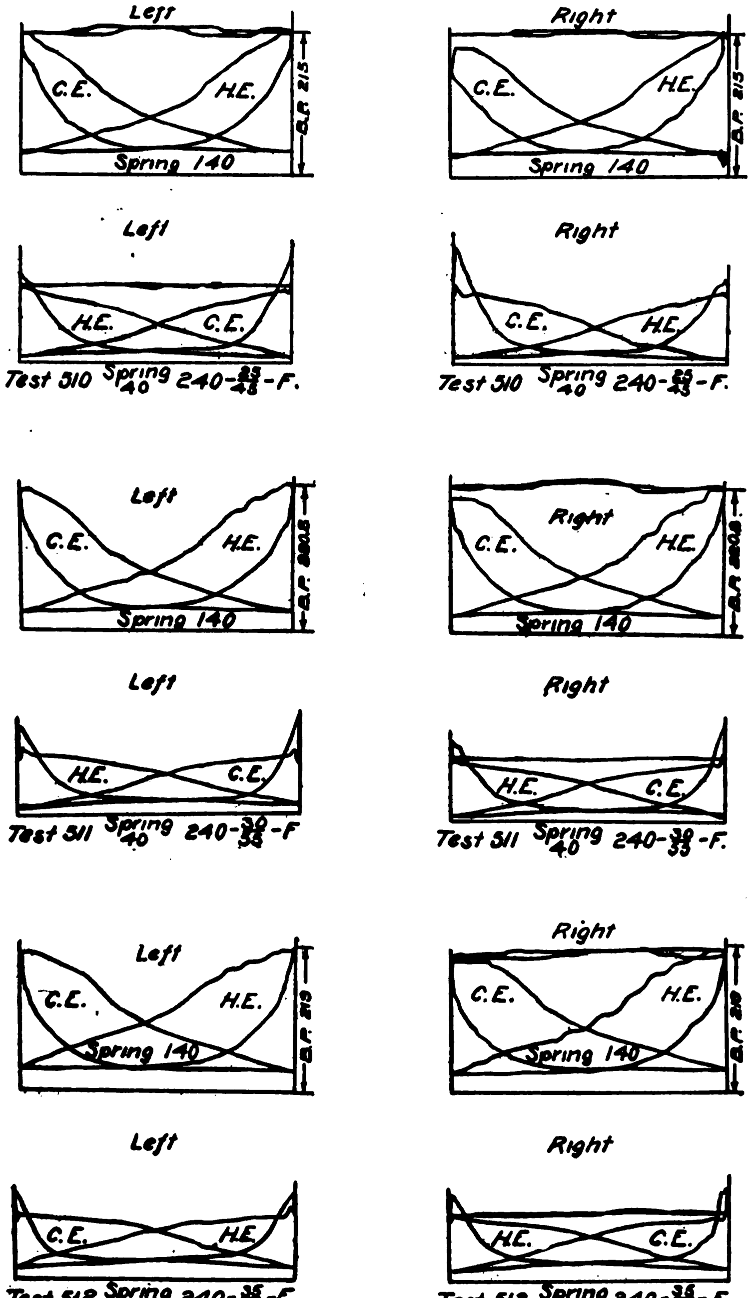
Nosing Diagrams, Locomotive No. 2512.



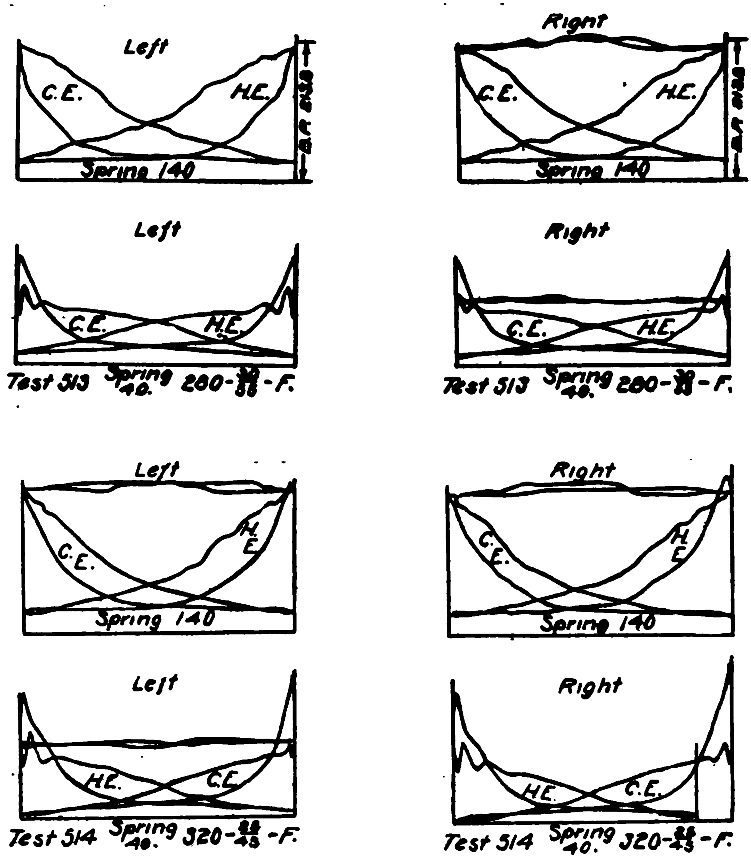
Typical Indicator Diagrams, Locomotive No. 2512.



Typical Indicator Diagrams, Locomotive No. 2512.

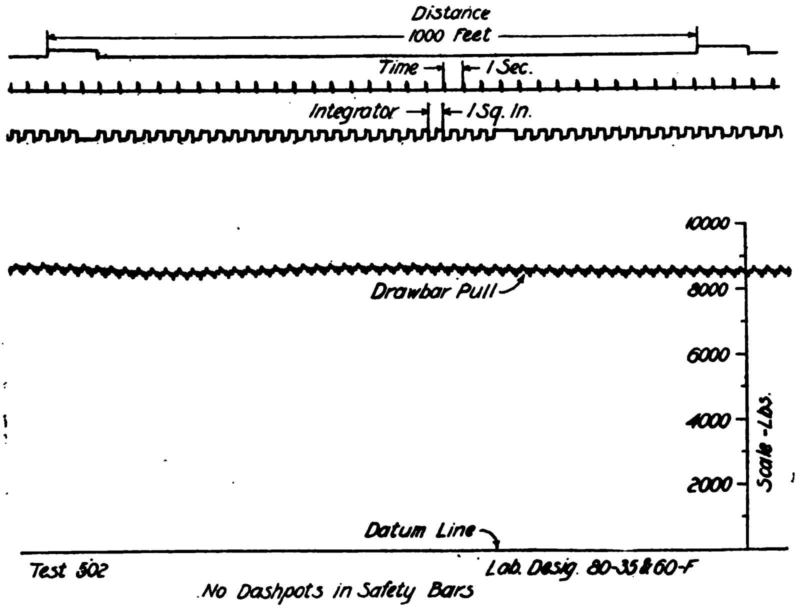


Typical Indicator Diagrams, Locomotive No. 2512.

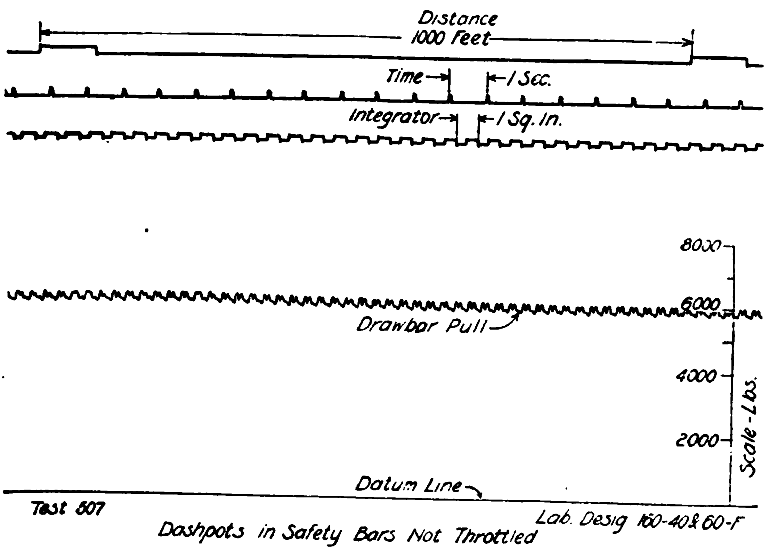


Test 514 not completed.

Typical Indicator Diagrams, Locomotive No. 2512.

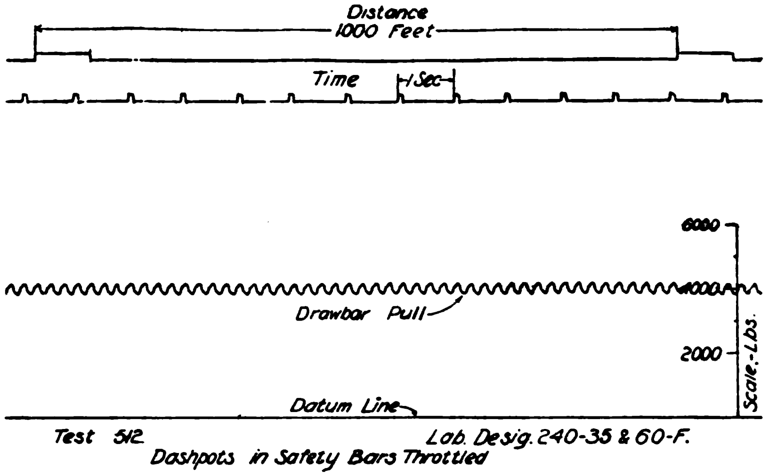


Speed, 19.14 Miles per Hour.

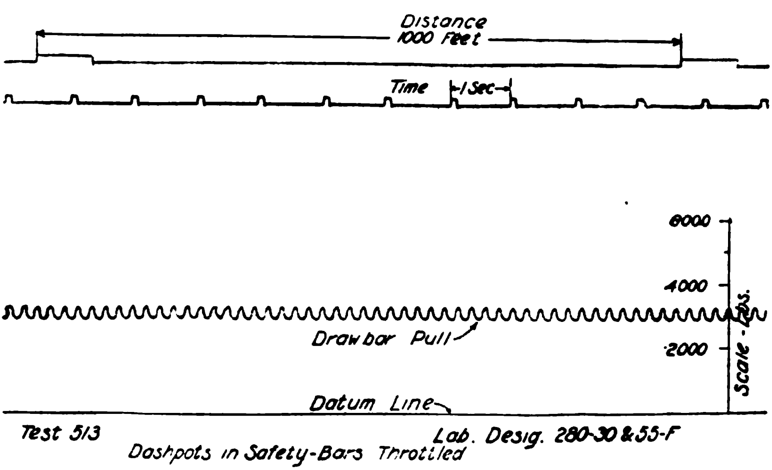


Speed, 38.26 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 2512.

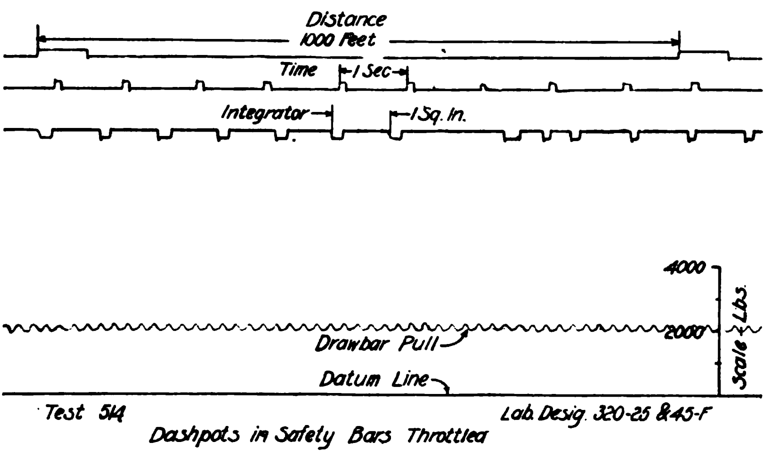


Speed, 57.39 Miles per Hour.



Speed, 66.96 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 2512.



Speed, 76.57 Miles per Hour.

Test 514 was not completed.

Typical Dynamometer Diagram, Locomotive No. 2512.

CHAPTER XVIII.

TESTS OF ATLANTIC TYPE LOCOMOTIVE, ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

The sixth locomotive tested was No. 535, owned by the Atchison, Topeka & Santa Fe Railway System and was built at the Baldwin Locomotive Works. It was of the 4-4-2 type and known as class 507 according to the railroad company's classification.

This was a Vauclain four-cylinder balanced compound locomotive of the type introduced by the Baldwin Locomotive Works. The two low pressure cylinders were outside of the frames and the two high pressure cylinders between them. All four cylinders were connected to the front axle. The high pressure crossheads were connected to a cranked axle in which the crank pins were set quartering or 90 degrees apart. The low pressure crossheads were connected to crank pins 90 degrees apart in the front drivers. On either side of the locomotive there was a high and a low pressure cylinder connected to cranks set opposite or at 180 degrees to each other. The high and low pressure cylinders were in line across the locomotive so that the high and low pressure connecting rods were of the same length.

The cut-off in the high and low pressure cylinders could not be varied independently, as the valves for each set of high and low pressure cylinders were actuated by a single valve gear.

The first official test on this locomotive was made on October 12.

Locomotive No. 535 occupied the time from October 9 to November 1, a period of twenty-four days. During that period eleven tests were made; the work being delayed by hot inside crank brasses on the locomotive. Four days were lost by troubles due to the plant and eight on account of the locomotive.

On October 27 an attempt was made to run a test at 320 revolutions, but after two minutes the babbitt melted out of the inside crank brasses. New brasses were put in and this test was again tried the next day, with the same result. As it appeared unlikely that a test could be run at 320 revolutions, a test at 280 revolutions was tried, with success. On October 31 a test at 320 revolutions failed after 10 minutes for the same reason as the others, and on November 1 the same thing occurred again. It was then decided to remove the locomotive from the plant, as four attempts at tests had failed at this speed, and it was evidently impossible to run it cool at this speed, on the testing plant.

This locomotive vibrated considerably at 240 revolutions, the movement of the pilot being about eight-tenths of an inch. The wires that were run under the wheels, to determine the effect of the counter-balance weights on rail pressure, showed that at 320 revolutions the driving wheel lifted from the supporting wheel a height of at least six-one-hundredths of an inch. A tendency to run to the right side was also noticed, the driving wheels bearing so hard against the right supporting wheels that the flanges of the drivers were badly cut. The locomotive was jacked over to the left, and wooden wedges driven in between the frame and trailer to hold it over, but the vibration of the locomotive soon loosened the wedges and the cutting of the flanges would commence again. The locomotive was squared, the wheels trammed, and the supporting wheels were correctly set. The circumference of the driving wheels on the right side was two-thousandths of a foot larger than on the left side.

The critical speed was found to be 180 revolutions.

The principal dimensions and the details of the locomotive are given in Appendix 600. The principal nominal dimensions are shown in the following table:

Total weight, pounds	201,500
Weight on drivers, pounds	99,200
Cylinders (compound), inches	15 & 25 x 26
Diameter of drivers, inches	79
Fire-box heating surface, square feet	220.3
Heating surface in tubes (water side), square feet	3016.71
Total heating surface (based on water side of tubes) square feet	3237.01

*Total heating surface (based on fire side of tubes), square feet	2902.05
Grate area, square feet	48.36
Boiler pressure, pounds	220
Valves	Piston
Link motion	Stephenson
Fire-box, type	Wagon top
Number of tubes	273
Outside diameter of tubes, inches	2.25
Length of tubes, inches	225.14

The maximum tractive effort was 26,182 pounds working simple and 19,245 pounds working compound, which was calculated on the assumption that 80 per cent. of the boiler pressure (220 pounds) was available as mean effective pressure at starting. On this basis the ratio of weight on drivers to maximum tractive effort was 3.79 : 1 working simple and 5.15 : 1 working compound.

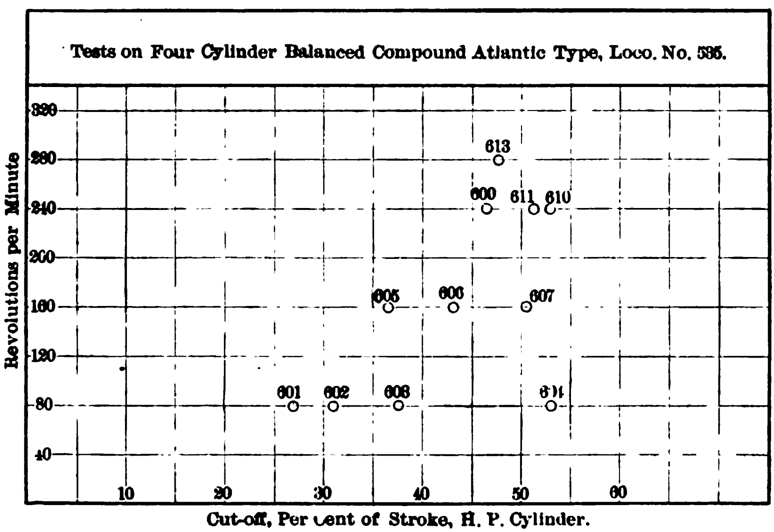


Fig. 601.

TESTS.

The tests which have been run, together with the laboratory designation and dates of running, are as follows:

* Used in Calculations.

Test No.	Laboratory Designation.	Date.
601	80-30-F	October 12th
602	80-35-F	" 14th
603	80-45-F	" 20th
604	80-55-F	" 20th
605	160-35-F	" 13th
606	160-45-F	" 17th
607	160-55-F	" 15th
609	240-50-F	" 17th
610	240-53-F	" 18th
611	240-53-F	" 22nd
613	280-50-F	" 31st

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 601.

The tests are arranged in order, according to the rate of

TABLE No. 601—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. of Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
601	80-30-F	180	217.6	14.556	68.6	68.6	54.92
602	80-35-F	180	215.7	14.645	55.3	66.2	73.47
603	80-45-F	180	221.0	14.400	55.7	64.1	86.44
604	80-55-F	180	220.4	14.534	56.9	58.5	128.83
605	160-35-F	111.5	220.6	14.617	59.3	67.0	79.96
606	160-45-F	180	219.2	14.523	66.0	65.7	154.74
607	160-55-F	180	221.9	14.564	64.2	66.2	204.28
609	240-50-F	120	221.2	14.490	73.2	65.6	186.35
613	280-50-F	90	219.5	14.603	55.2	55.5	160.18
610	240-53-F	73.26	211.4	14.469	73.3	64.6	148.70
611	240-53-F	120	221.0	14.496	56.0	62.4	237.96

equivalent evaporation. No recorded test was shorter than 73.26 minutes, while the longest was 180 minutes.

The lowest average boiler pressure was 211.4 pounds, while the highest was 221.9 pounds. The temperature of the feed water was very uniform. The total coal fired per square foot of grate area follows:

In 4 tests ....between 50 and 100 lbs.
In 2 tests ....between 100 and 150 lbs.
In 3 tests ....between 150 and 200 lbs.
In 2 tests ....more than 200 lbs.

EVAPORATION—TABLE 602

The evaporation per hour was between the limits of 8,958 pounds and 34,126 pounds.

TABLE No. 602—EVAPORATION.

Identification of Test		Duration of Test, Minutes	Water and Steam		Calorimeter Results			Equivalent Evaporation Lbs. Per Hour
Test Number	Laboratory Designation		Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Quality of steam in Branch Pipe	Degrees Superheat in Branch Pipe	
		Cal.	264	340	*228	229	230	344
601	80-30-F	180	26875	8958	.9823	.9872	0	10656
602	80-35-F	180	32808	10936	.9814	.9868	0	13012
603	80-45-F	180	39313	13104	.9808	.9859	0	15638
604	80-55-F	180	51838	17279	.9811	.9875	0	20713
605	160-35-F	111.5	32996	17748	.9809	.9805	0	21128
606	160-45-F	180	62574	20858	.9820	.9882	0	24885
607	160-55-F	180	77771	25924	.9817	.9893	0	30900
609	240-50-F	120	58139	29070	.9819	.9884	0	34668
613	280-50-F	90	46657	31102	.9808	.9903	0	37463
610	240-53-F	73.26	40975	33563	.9626	.9824	0	39589
611	240-53-F	120	68251	34126	.9796	.9903	0	40964

There was a slight tendency for the moisture to increase as the rate of evaporation increased.

BOILER POWER—TABLE 603.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 220.4 to 847.1.

The equivalent evaporation per square foot of heating surface ranged from 3.67 to 14.11 pounds per hour.

The maximum boiler horse power developed was 1,187.2, the horse power being calculated on the usual basis.

The horse power developed per square foot of heating surface ranged from .106 to .409.

TABLE No. 603—BOILER POWER.

Identification of Test		Duration of Test, Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft. of Grate Surface
		Cal.	Cal.	345	349	Cal.	Cal.
601	80-30-F	180	220.4	3.67	308.9	.106	6.39
602	80-35-F	180	269.1	4.48	377.2	.130	7.80
603	80-45-F	180	323.4	5.39	453.3	.156	9.37
604	80-55-F	180	428.4	7.14	600.4	.207	12.42
605	160-35-F	111.5	436.9	7.28	612.4	.211	12.66
606	160-45-F	180	514.6	8.58	721.3	.249	14.92
607	160-55-F	180	639.0	10.65	895.7	.309	18.52
609	240-50-F	120	716.9	11.95	1004.7	.346	20.78
613	280-50-F	90	774.7	12.91	1085.8	.374	22.45
610	240-53-F	73.26	817.6	13.62	1145.9	.395	23.70
611	240-53-F	120	847.1	14.11	1187.2	.409	24.55

TABLE No. 604—COAL AND RATE OF COMBUSTION.

Identification of Test		Duration of Test, Minutes	Total Dry Coal Fired	Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation			Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq.Ft. of Grate Per Hour	Dry Coal Per Sq.Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
601	80-30-F	180	2626	2467	875	822	18.10	.301
602	80-35-F	180	3507	3303	1169	1101	24.17	.403
603	80-45-F	180	4142	3836	1381	1279	28.50	.476
604	80-55-F	180	6175	5829	2058	1943	42.56	.709
605	160-35-F	111.5	3820	3589	2055	1931	42.49	.708
606	160-45-F	180	7403	6941	2468	2313	51.03	.850
607	160-55-F	180	9773	8992	3258	2997	67.36	1.123
609	240-50-F	120	8905	8380	4452	4190	92.06	1.534
613	280-50-F	90	7656	7225	5104	4817	105.52	1.759
610	240-53-F	73.26	7120	6614	5831	5417	120.57	2.009
611	240-53-F	120	11401	10717	5701	5358	117.87	1.965

The maximum horse power developed per square foot of grate surface was equivalent to about one horse power for each .040 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 604.

The total coal fired ranged from 2,626 pounds to 11,401 pounds, and the amount per hour 875 pounds to 5,831 pounds.

The dry coal fired per square foot of grate area per hour ranged from 18.10 pounds to 120.57 pounds. The increase in the rate of combustion was regular.

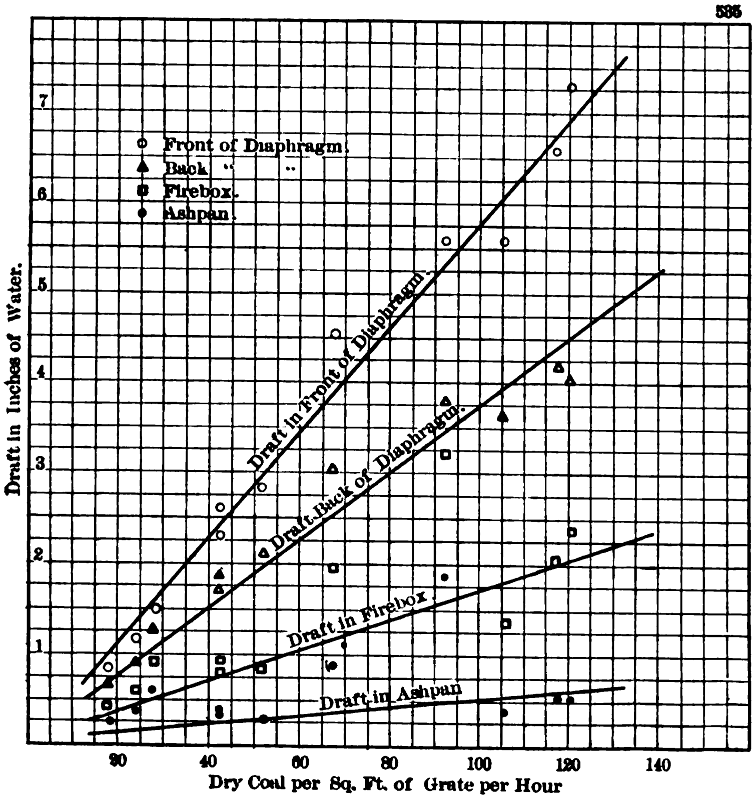


Fig. 602.— Draft and Rate of Combustion.

The coal burned per square foot of heating surface per hour ranged from .301 to 2.009 pounds.

CINDERS AND SPARKS—TABLE 605.

The maximum calorific value of the cinders was 13,438 B.

TABLE No. 605—CINDERS AND SPARKS.

Identification of Test		Duration of Test, Minutes	Total in Lbs. Per Hour			Calorific Value, B.T.U Per Lb.	
Test Number	Laboratory Designation		Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
601	80-30-F	180	20.7	8.7	29.3	11305	10452
602	80-35-F	180	5.3	0	5.3	11519	10665
603	80-45-F	180	12.7	18.3	31.0	12165	11945
604	80-55-F	180	15.7	88.3	104.0	12585	11732
605	160-35-F	111.5	25.3	40.9	66.2	11092	10452
606	160-45-F	180	7.7	60.0	67.7	11305	10452
607	160-55-F	180	12.0	88.7	100.7	11092	10452
609	240-50-F	120	75.5	185.5	261.0	12585	12159
613	280-50-F	90	97.3	272.0	369.3	13225	12799
610	240-53-F	73.26	140.9	360.3	501.2	13438	13225
611	240-53-F	120	12.0	178.5	190.5	13225	13012

TABLE No. 606—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water				Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In Front of Diaphragm	Back of Diaphragm	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	223	224	225	212	207	339
601	80-30-F	180	.83	.67	.43	.25	1476	500	18.10
602	80-35-F	180	1.18	.91	.60	.37	1607	515	24.17
603	80-45-F	180	1.50	1.28	.95	.60	1762	530	28.50
604	80-55-F	180	2.62	1.87	.91	.41	1882	560	42.56
605	160-35-F	111.5	2.30	1.70	.77	.37	1835	571	42.49
606	160-45-F	180	2.84	2.05	.82	.29	1793	577	51.08
607	160-55-F	180	4.54	3.02	1.97	.89	1975	625	67.36
609	240-50-F	120	5.59	3.79	3.20	1.86	1946	652	92.06
613	280-50-F	90	5.58	3.64	1.35	.35	2177	660	105.52
610	240-53-F	73.26	7.27	4.01	2.44	.53	1997	669	120.57
611	240-53-F	120	6.59	4.16	2.02	.53	2162	689	117.87

T. U., and the maximum calorific value of the sparks was 13,225 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 606.

The methods employed in obtaining the relations between the several factors plotted in Figs. 602 to 604 inclusive, have already been explained in Chapter XIII. The equations for this locomotive are given below:

$$D = .0576\ G \quad (601)$$
$$T_f = 4.25\ G + 1610 \quad (602)$$
$$T_s = 1.81\ G + 475 \quad (603)$$
$$T_f - T_s = 2.44\ G + 1135 \quad (604)$$
$$H = .098\ G + 2.8 \quad (605)$$
$$G = .410\ (T_f - T_s) - 465 \quad (606)$$
$$G = 10.20\ H - 28.5 \quad (607)$$
$$H = .04\ (T_f - T_s) - 42.78 \quad (608)$$

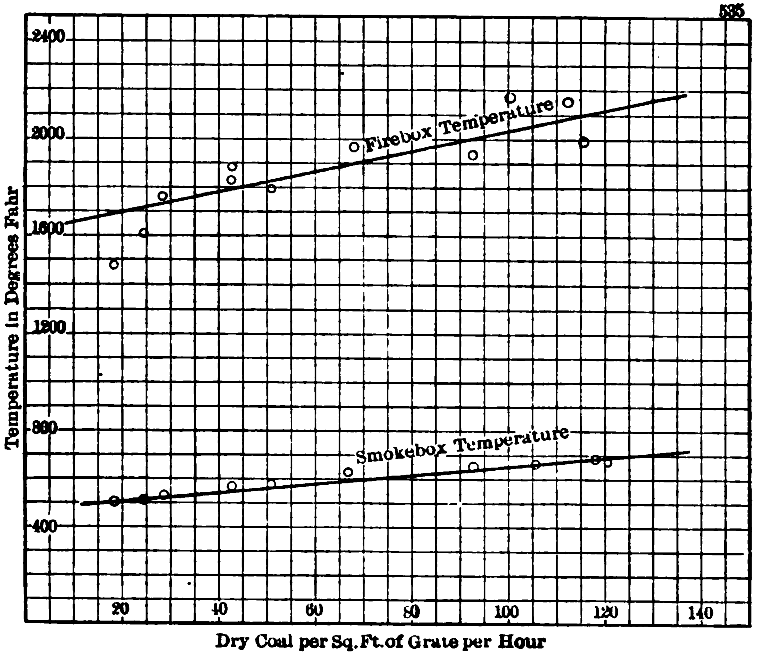


Fig. 603.— Fire-box and Smoke-box Temperatures.

The fire-box temperatures ranged from 1,476 to 2,177 de-

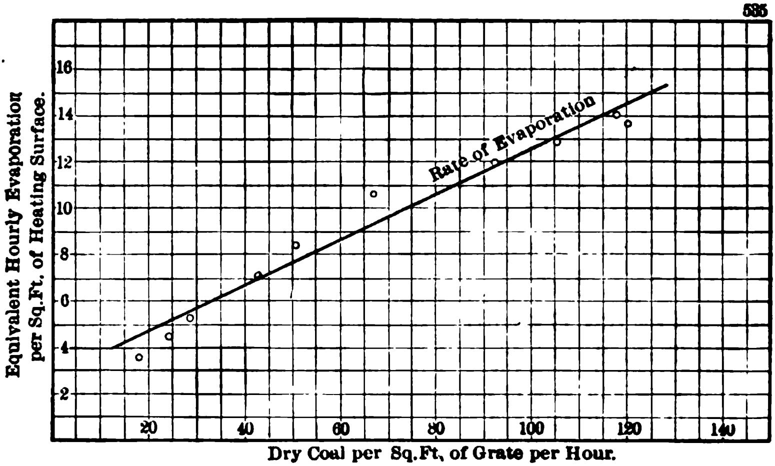


Fig. 604.— Rates of Combustion and Evaporation.

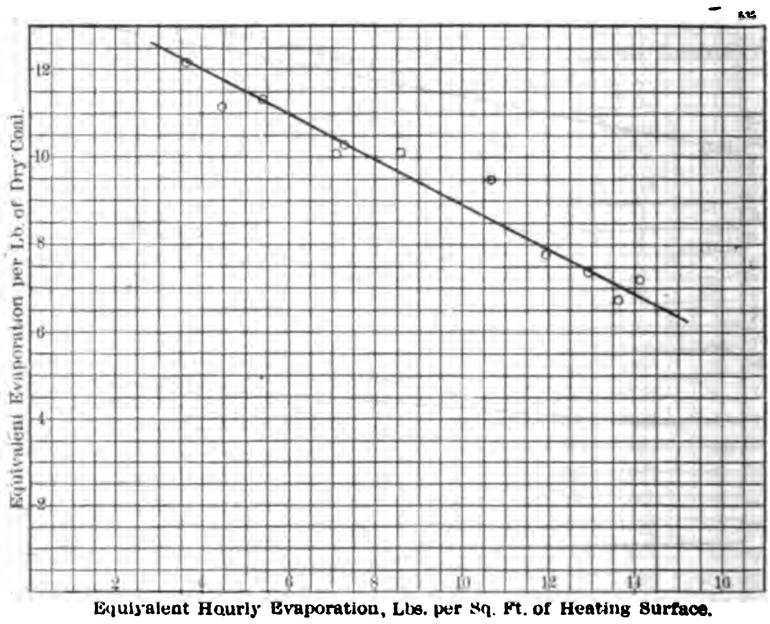


Fig. 605.— Rate of Evaporation and Evaporation per Lb. of Coal.

grees Fahrenheit, and the smoke-box temperatures ranged from 500 to 689 degrees Fahrenheit.

EVAPORATIVE PERFORMANCES—TABLE 607.

The equivalent evaporation per pound of dry coal ranged from 12.17 pounds to 6.78 pounds.

The heating value of the coal was practically uniform for all the tests.

The efficiency of the boiler dropped rapidly as the rate of evaporation increased, the range being between the rather wide limits of 78.43 per cent. and 44.05 per cent.

TABLE No. 607—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
601	80–30–F	180	10.12	12.17	12.96	14992	78.43
602	80–35–F	180	9.23	11.18	11.82	15128	71.06
603	80–45–F	180	9.40	11.33	12.23	14853	73.65
604	80–55–F	180	8.32	10.06	10.66	15067	64.50
605	160–35–F	111.5	8.53	10.28	10.92	15008	66.16
606	160–45–F	180	8.36	10.09	10.76	14986	64.99
607	160–55–F	180	7.87	9.49	10.31	14663	62.48
609	240–50–F	120	6.45	7.79	8.27	15005	50.12
613	280–50–F	90	6.03	7.34	7.78	14996	47.27
610	240–53–F	73.26	5.70	6.78	7.30	14868	44.05
611	240–53–F	120	5.93	7.19	7.65	15070	46.05

From Fig. 605 the relation between E and H was found to be:

$$E = 14.10 - .517H \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (609)$$

SMOKE-BOX GASES—TABLE 608.

There was a tendency for the oxygen to decrease as the rate of evaporation increased—the range for the several tests being between the limits of 8.50 per cent. and 2.13 per cent.

The percentage of CO increased as the rate of evaporation increased—the range for this locomotive being between the limits of 0.0 per cent. and 1.15 per cent.

TABLE No. 608—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
601	80-30-F	180	8.50	.0	10.63	80.87	14825	0
602	80-35-F	180	6.87	.0	11.73	81.40	14932	0
603	80-45-F	180	6.20	.13	11.93	81.74	14720	.63
604	80-55-F	180	7.30	.0	11.50	81.20	14932	0
605	160-35-F	111.5	7.60	.10	11.55	80.75	14827	.49
606	160-45-F	180	5.70	.07	12.73	81.50	14822	.32
607	160-55-F	180	5.13	.17	12.70	82.00	14506	.78
609	240-50-F	120	5.20	.53	11.97	82.30	14827	2.44
613	280-50-F	90	2.13	.40	14.13	83.34	14826	1.60
610	240-53-F	73.26	2.75	1.15	13.45	82.65	14720	4.57
611	240-53-F	120	5.27	.50	12.07	82.16	14931	2.27

TABLE No. 609—GENERAL ENGINE CONDITIONS.

Identification of Test		Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke H. P. Cylinder	Steam Pressure	
Test Number	Laboratory Designation					In Boiler Lbs. Per Sq. In.	In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	217	220
601	80-30-F	180	80.00	18.79	26.7	217.6	210.0
602	80-35-F	180	80.00	18.79	31.0	215.7	208.1
603	80-45-F	180	80.00	18.79	37.6	221.0	213.4
604	80-55-F	180	80.01	18.79	53.0	220.4	212.0
605	160-35-F	111.5	160.00	37.59	36.1	220.6	211.4
606	160-45-F	180	160.00	37.59	43.0	219.2	210.4
607	160-55-F	180	160.00	37.59	50.5	221.9	211.8
609	240-50-F	120	239.89	56.35	46.4	221.2	211.5
611	240-53-F	120	240.02	56.38	51.3	221.0	210.3
610	240-53-F	73.26	239.96	56.37	52.9	211.4	200.3
613	280-50-F	90	280.00	65.77	47.7	219.5	209.3

The carbon dioxide, CO_2, ranged from 10.63 per cent. to 14.13 per cent.

The heat lost by imperfect combustion ranged from 0.0 per cent. to 4.57 per cent.

PERFORMANCE OF ENGINES.

GENERAL ENGINE CONDITIONS—TABLE 609.

The lowest speed at which any test was run was 18.79 miles per hour, while the highest speed was 65.77 miles per hour. It

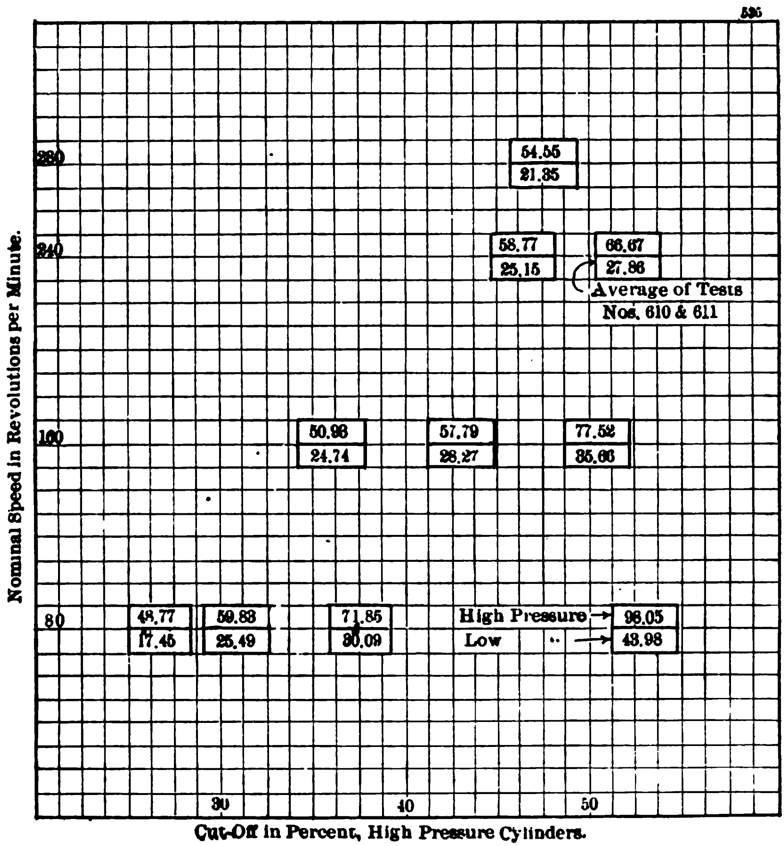


Fig. 606.— Mean Effective Pressure.

was found impossible to run the locomotive for any length of time at 320 revolutions per minute, on account of the inside, or high pressure, main rod bearings heating at the crank pin end.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 610.

The best performance of the engines was at 50.5 per cent. cut-off and 160 revolutions per minute (about 37½ miles per hour), under which conditions the steam consumption was 19.41 pounds per indicated horse power hour.

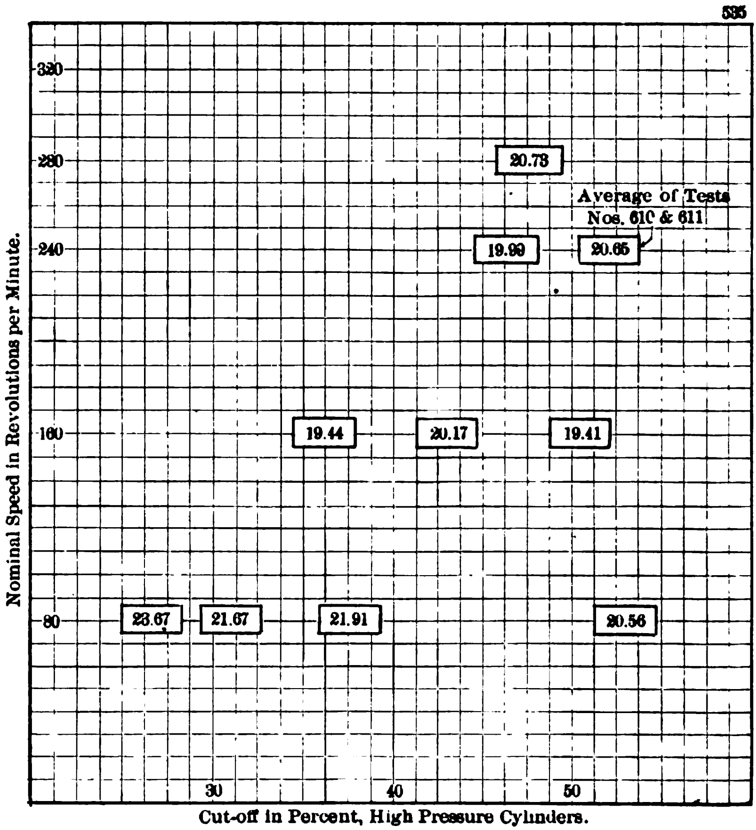


Fig. 607.— Dry Steam per I. H. P. Hour.

The highest indicated horse power was 1,621.5, which was obtained at 51.3 per cent. cut-off and a nominal speed of 240 revolutions per minute.

TABLE No. 610—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test		Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch		Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
Test Number	Laboratory Designation		H. P. Cyl.	L. P. Cyl.		
		Cal.	Cal.	Cal.	379	381
601	80-30-F	180	48.8	17.5	356.2	23.67
602	80-35-F	180	59.8	25.5	479.0	21.67
603	80-45-F	180	71.9	30.1	570.4	21.91
604	80-55-F	180	98.1	44.0	808.4	20.56
605	160-35-F	111.5	50.9	24.7	877.1	19.44
606	160-45-F	180	57.8	28.3	999.9	20.17
607	160-55-F	180	77.5	35.7	1296.1	19.41
609	240-50-F	120	58.8	25.2	1414.6	19.99
611	240-53-F	120	67.8	28.6	1621.5	20.48
610	240-53-F	73.26	65.6	27.1	1549.4	20.82
613	280-50-F	90	54.6	21.4	1459.7	20.73

TABLE No. 611—DYNAMOMETER RECORDS.

Identification of Test		Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D. H. P. Hour
Test Number	Laboratory Designation					
		Cal.	265	383	384	385
601	80-30-F	180	6058	303.5	2.75	27.77
602	80-35-F	180	7847	393.2	2.86	26.39
603	80-45-F	180	9998	501.0	2.66	24.94
604	80-55-F	180	12815	642.3	3.12	25.88
605	160-35-F	111.5	7533	755.0	2.65	22.59
606	160-45-F	180	8708	872.7	2.77	23.11
607	160-55-F	180	11119	1114.4	2.87	22.58
609	240-50-F	120	6803	1022.3	4.29	27.66
611	240-53-F	120	8444	1269.8	4.43	26.15
610	240-53-F	73.26	8679	1304.6	4.41	24.73
613	280-50-F	90	5120	898.0	5.60	33.70

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 611.

The maximum average recorded draw-bar pull was 12,815 pounds at a speed of 80 revolutions per minute and a high pressure cut-off of 53 per cent.

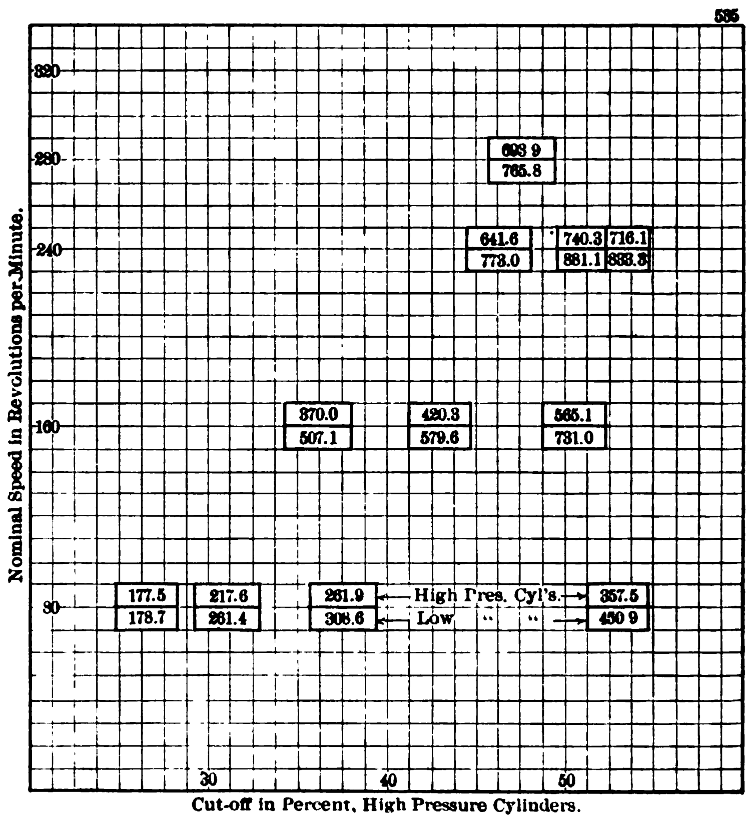


Fig. 608.— Total Indicated Horse Power.

The maximum dynamometer horse power was 1,304.6 which was obtained at a speed of 240 revolutions per minute and a high-pressure cut-off of 53 per cent.

The general tendency was for the coal per dynamometer horse power hour to increase as the speed increased. The minimum coal rate obtained was 2.65 pounds and the maximum rate was 5.60 pounds per dynamometer horse power hour.

The lowest steam consumption was 22.58 pounds per dynamometer horse power hour, which was obtained at a speed of 160

TABLE No. 612—MACHINE FRICTION.

Identification of Test		Duration of Test, Minutes	Machine Friction in		Machine Efficiency Per Cent.
Test Number	Laboratory Designation		Horse Power	Draw-Bar Pull Pounds	
		Cal.	395	397	398
601	80-30-F	180	52.69	1057	85.22
602	80-35-F	180	85.77	1720	82.10
603	80-45-F	180	69.37	1391	87.84
604	80-55-F	180	166.10	3309	79.46
	Average		93.48	1869	
605	160-35-F	111.5	122.06	1224	86.08
606	160-45-F	180	127.15	1275	87.28
607	160-55-F	180	181.69	1822	85.99
	Average		143.63	1440	
609	240-50-F	120	392.31	2623	72.27
611	240-58-F	120	351.66	2350	78.31
610	240-58-F	73.26	244.79	1636	84.20
	Average		329.59	2203	
613	280-50-F	90	561.65	3218	61.53

revolutions per minute and a high-pressure cut-off of 50.5 per cent.

MACHINE FRICTION—TABLE 612.

The machine efficiency ranged from 61.53 per cent. to 87.84 per cent.

MAXIMUM POWER OF LOCOMOTIVE.

The maximum evaporative power of the boiler, as disclosed by these tests, was between 32,500 and 33,500 pounds of steam per hour, which is equivalent to a rate of evaporation of between 11 and 12 pounds per square foot of heating surface per hour.

In Fig. 611 is shown the maximum draw-bar pull of this lo-

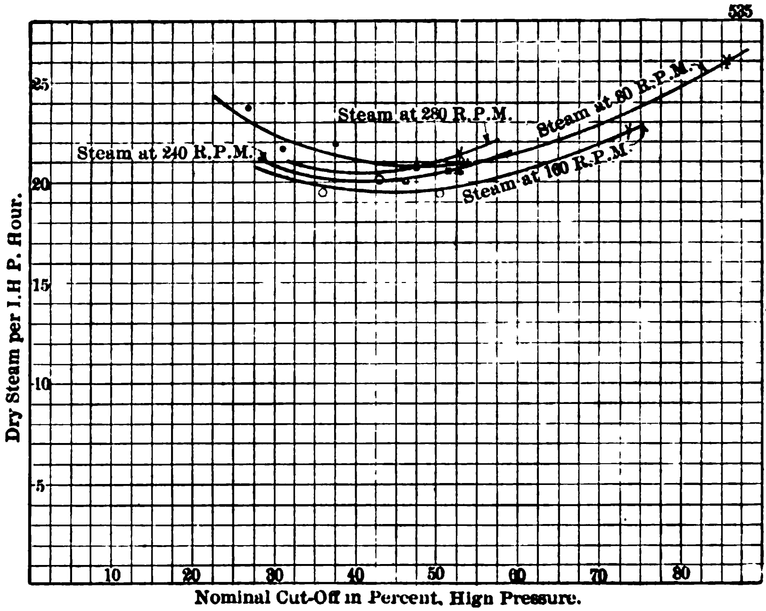
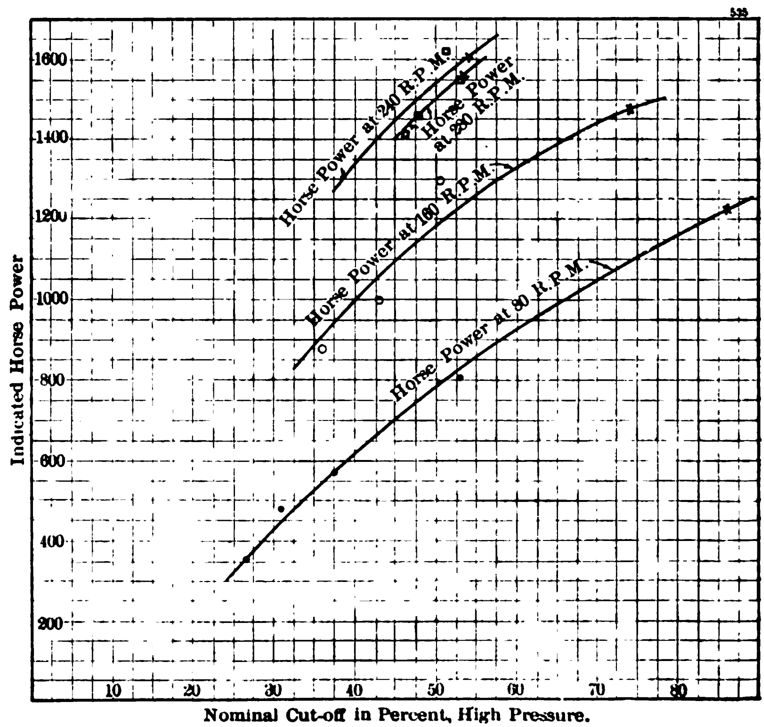


Fig. 609.— Steam Consumption.



comotive as limited by the cylinder power and the maximum evaporation of the boiler. The method of obtaining this curve is fully explained in Chapter XIII, page 143.

The critical cut-off, the steam consumption and the maxi-

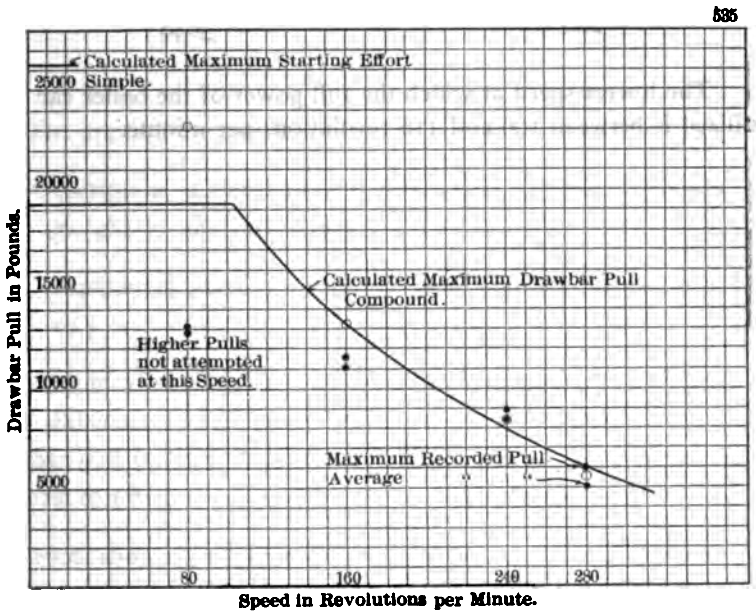


Fig. 611.—Maximum Draw-bar Pull.

mum cylinder horse power, as disclosed by Figs. 609 and 610 are given in the following table:

Nominal Speed In R. P. M.	Cut-off in Per Cent.	Steam per Indicated Horse Power Hour.	Maximum Cylinder Horse Power.
80	86	26.6	1255
160	74	22.6	1470
240	54	20.8	1605
280	53	21.4	1555

The equivalent draw-bar pull, minus friction at each speed shown above is given in the following table:

Speed in R. P. M.	Maximum Estimated Draw-Bar Pull. Pounds.
80	23178
160	13225
240	8472
280	5648

The lowest speed at which the full power of the boiler can be utilized is between 100 and 110 revolutions per minute.

APPENDIX 600.

The appendix contains.

1. Description, dimensions and proportions of the locomotive. (pp. 484 to 489 inclusive.)

2. Summary of average results of tests. (pp. 490 to 500 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and drawbar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 501 to 506 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 507 to 522 inclusive.)

5. Vibration diagrams. (pp. 523 to 533 inclusive.)

6. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 534 to 537 inclusive.)

7. A typical dynamometer diagram for each nominal speed. (pp. 538 and 540.)

8. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of Atchison Atlantic (4-4-2) Type Locomotive No. 535.

Built by the Baldwin Locomotive Works, Philadelphia Pa., 1904.

DRIVING WHEELS.

1	Number of pairs	2
2	Approximate diameter, inches	79

MEASURED CIRCUMFERENCE, FEET.

3	Right, No. 1	20.668
4	" " 2	20.669
5	" " 3	——
6	" " 4	——
7	" " 5	——
8	Left, " 1	20.676
9	" " 2	20.676
10	" " 3	——
11	" " 4	——
12	" " 5	——
13	Average	20.672

ENGINE TRUCK WHEELS.

14	Number	4
15	Diameter, inches	34.25

TRAILING WHEELS.

16	Diameter, inches	50.2

WHEEL BASE, FEET.

17	Driving wheel base	6.834
18	Total wheel base	30.288
19	Gauge of wheels, in inches	56.125

WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.

20	On truck	51,880
21	" 1st drivers	52,000
22	" 2nd "	47,200
23	" 3rd "	——
24	" 4th "	——
25	" 5th "	——
26	" trailers	50,420
27	Total	201,500
28	" on drivers	99,200

CYLINDERS.

29	High pressure, number	2
30	Low " "	2
31	Arrangement, L. P. outside; H. P. inside; Vauclain comp.	

DIAMETER, INCHES.

32	High pressure, right	15.034
33	" " left	15.037
34	Low " right	25.023
35	" " left	25.020

STROKE OF PISTON, FEET.

36	High pressure, right	2.166
37	" " left	2.167
38	Low " right	2.167
39	" " left	2.169

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P., right, head end	17.80
41	" " crank "	19.10
42	" left, head "	18.20
43	" " crank "	19.20
44	L. P., right, head "	6.40
45	" " crank "	6.58
46	" left, head "	6.58
47	" " crank "	6.77

RECEIVER, CUBIC FEET.

48	Volume, right side	3.07
49	" left "	3.05

STEAM PORTS, INCHES.

(*For piston valves the length equals the circumference of inside of bushing, minus the sum of the widths of bridges.*)

50	H. P. admission, right, head end, length	36.33
51	" " " " " width	1.50
52	" " " crank " length	36.33
53	" " " " " width	1.50
54	" " left, head " length	36.40
55	" " " " " width	1.50
56	" " " crank " length	36.40
57	" " " " " width	1.50
58	L. P. " right, head " length	36.33
59	" " " " " width	1.50
60	" " " crank " length	36.33
61	" " " " " width	1.50
62	" " left, head " length	36.40
63	" " " " " width	1.50
64	" " " crank " length	36.40
65	" " " " " width	1.51
66	H. P. exhaust, right, length	47.18
67	" " " width	2.00
68	" " left, length	47.20
69	" " " width	2.00
70	L. P. " right. length	36.33

71	L. P. exhaust, right, width	1.45
72	" " left, length	36.40
73	" " " width	1.45

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	3.255
75	" " left	3.245
76	Low " right	3.245
77	" " left	3.235

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	" " left	——
80	Low " right	——
81	" " left	——

VALVES.

82	Type	piston
83	Design	Baldwin Locomotive Works
84	Per cent. of balanced to total area	H.P. 70.59; L.P. 75.31
85	Type of link motion	Stephenson, open rods

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	4.4
87	" " left	4.5
88	Low " right	4.4
89	" " left	4.5

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure, right, head end	1.01
91	" " " crank "	1.01
92	" " left, head "	1.00
93	" " " crank "	1.00
94	Low " right, head "	.85
95	" " " crank "	.86
96	" " left, head "	.89
97	" " " crank "	.84

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	negative	.26
99	" " " crank "	"	.26
100	" " left, head "	"	.25
101	" " " crank "	"	.25
102	Low " right, head "	"	.35
103	" " " crank "	"	.36
104	" " left, head "	"	.39
105	" " " crank "	"	.35

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	sheet iron
108	Lead, forward motion, inches	H. P., o.; L. P., .125
109		
110		
111		
112		

BOILER.

113	Type	Wagon top, radial stay, wide fire box
114	Outside diameter, 1st ring, inches	69.

TUBES.

115	Number	273.
116	Outside diameter, inches	2.25
117	Thickness, inches	.125
118	Length between tube sheets, inches	225.137
119	Total fire area, square feet	5.955
120	Serve tubes, number of ribs	——
121	" " sq. in, of inside surface in one in. of length	——
122		
123		
124	Boiler pressure, pounds per sq. in.	220

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129		
130		
131		

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	115.44
133	Width	65.94
134	Depth, front end	73.80
135	" back "	66.06
136	Volume, cubic feet (less arch and tubes)	282.25
137	Air inlets to ash pan, (dampers closed,) sq. ft.	.0
138	" " " " " (" open,) " "	6.49
139		
140		

FIRE DOORS.

141	Number	one
142	Area, square feet	1.83
143		

GRATES.

144	Style	rocking finger
145	Total area, square feet	48.36
146	" " dead grates, square feet	0
147	Width of air spaces, inches	1.06

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	0.
149	" grates	17.93
150	" fire doors	.06
151	Total air inlets, (148), (149) and (150)	17.99
152	Ratio " " (149) to grate area (145)	.371
153	" " " (151) " " " (145)	.372

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	3016.71
155	" " " fire "	2681.75
156	" " firebox, fire side,	220.30
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	2902.05
159	Total, based on inside of firebox and outside of tubes	3237.01

BOILER VOLUMES.

(With water surface at level of second gauge cock.)

160	Water space, cubic feet	434.50
161	Steam " "	54.85

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	5.75
164	" " left, "	
165	Area of right, square inches	——
166	" " left, " "	——
167	Total area, square inches	25.97

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	17
169	L. P. " " " " "	
170		

RATIOS.

171	Heating surface (158) to grate area (145)......	60.010
172	Fire area through tubes (119) to grate area (145)	.123
173	Firebox heating surface (156) to grate area (145)	4.556
174	Tube surface (155) to firebox heating surface (156)..	12.173
175	Firebox volume (136) to grate area (145)......	5.837
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(power developed at one R. P. M. when pull is one pound.)

179	....	.0006264

CONSTANTS FOR INDICATED HORSE POWER

(power developed at one R. P. M. and one pound M. E. P.)

180	High	pressure	cylinder,	right,	head	end	.011652
181	"	"	"	"	crank	"	.011106
182	"	"	"	left,	head	"	.011662
183	"	"	"	"	crank	"	.011118
184	Low	"	"	right,	head	"	.032293
185	"	"	"	"	crank	"	.031750
186	"	"	"	left,	head	"	.032316
187	"	"	"	"	crank	"	.031776

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head	end	2.6702
189	"	"	"	"	crank	"	2.5450
190	"	"	"	left,	head	"	2.6724
191	"	"	"	"	crank	"	2.5480
192	Low	"	"	right,	head	"	7.4006
193	"	"	"	"	crank	"	7.2761
194	"	"	"	left,	head	"	7.4056
195	"	"	"	"	crank	"	7.2818

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed				Position of Levers				
			Revolutions		Equivalent						
			Total	Average Per Minute	Speed in Miles Per Hour	Piston Speed in Feet Per Minute	Reverse, Notches From Front End		Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	
		196	197	198	199	200	201	202	203	204	205
601	80–30–F	3.000	14400	80.00	18.79	346.8	16		FULL	42	
602	80–35–F	3.000	14400	80.00	18.79	346.8	15		"	45	
603	80–45–F	3.000	14400	80.00	18.79	346.8	13		"	47	
604	80–55–F	3.000	14402	80.01	18.79	346.8	10		"	52	
605	160–35–F	1.859	17600	160.00	37.59	693.6	15		"	54	
606	160–45–F	3.000	28800	160.00	37.59	693.6	13		"	51	
607	160–55–F	3.000	28800	160.00	37.59	693.6	11		"	55	
609	240–50–F	2.000	28787	239.89	56.35	1039.7	12		"	66	
610	240–53–F	1.221	16797	239.96	56.37	1040.1	11		"	75	
611	240–53–F	2.000	28802	240.02	56.38	1040.4	11		"	74	
613	280–50–F	1.500	25200	280.00	65.77	1213.6	12		"	70	

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of								Horizontal Vibration at Front of Engine Inches	Horizontal Vibration at Back of Engine Inches	Steam lost from Boiler, etc. Lbs. per hour
		Smoke Box		Laboratory								
		By Thermometer	By Pyrometer	Dry Bulb	Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer				
		206	207	208	209	210	211	212	213	214	215	216
601	80–30–F	480	500	68.6	59.1	391.6	68.6	1476		——	—	421
602	80–35–F	496	515	55.3	51.0	390.9	66.2	1607		*.17	.08	416
603	80–45–F	508	530	55.7	42.4	392.9	64.1	1762		*.20	.10	436
604	80–55–F	548	560	56.9	47.6	392.4	58.5	1882		——	.11	429
605	160–35–F	552	571	59.3	53.0	392.2	67.0	1835		*.52	—	458
606	160–45–F	559	577	66.0	52.4	391.8	65.7	1793		*.57	.09	423
607	160–55–F	598	625	64.2	53.9	392.3	66.2	1975		*.56	—	432
609	240–50–F	628	652	73.2	60.6	392.2	65.6	1946		*.76	.50	425
610	240–53–F	668	669	73.3	60.3	387.8	64.6	1997		*.74	.34	419
611	240–53–F	661	689	56.0	44.5	391.7	62.4	2162		*.74	.59	435
613	280–50–F	644	660	55.2	49.3	391.4	55.5	2177		*.74	—	423

* Engine Blocked.

For date of test, see item 407.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

Atchison, Topeka & Santa Fe Railway System.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	Pressure: In Boiler: Maximum	Pressure: In Boiler: Minimum	Pressure: In Branch Pipe	Pressure: Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box: Front of Diaphragm.	Draft: In Smoke Box: Back of Diaphragm.	Draft: In Fire Box	Draft: In Ash Pan	Injectors: Hours in Action: Total, Right	Injectors: Hours in Action: Total, Left
		217	218	219	220	221	222	223	224	225	226	227
601	80-30-F	217.6	220.1	215.7	210.0	14.556	.83	.67	.43	.25	0	1.138
602	80-35-F	215.7	217.7	213.0	208.1	14.645	1.18	.91	.60	.37	0	1.414
603	80-45-F	221.0	223.0	219.2	213.4	14.400	1.50	1.28	.95	.60	.036	1.643
604	80-55-F	220.4	221.7	219.0	212.0	14.534	2.62	1.87	.91	.41	0	2.172
605	160-35-F	220.6	222.3	218.8	211.4	14.617	2.30	1.70	.77	.37	0	1.153
606	160-45-F	219.2	221.9	211.5	210.4	14.523	2.84	2.05	.82	.29	0	2.760
607	160-55-F	221.9	224.0	216.5	211.8	14.564	4.54	3.02	1.97	.89	0	2.928
609	240-50-F	221.2	224.2	213.0	211.5	14.490	5.59	3.79	3.20	1.86	.188	1.982
610	240-53-F	211.4	223.3	200.7	200.3	14.469	7.27	4.01	2.44	.53	.292	1.228
611	240-53-F	221.0	222.6	215.5	210.3	14.496	6.59	4.16	2.02	.53	.406	1.994
613	280-50-F	219.5	222.9	218.0	209.3	14.603	5.58	3.64	1.35	.35	.084	1.500

Test Number	Laboratory Designation	Quality of steam: In Dome	Quality of steam: In Branch Pipe	Quality of steam: Degrees of Superheat in Branch Pipe	Quality of steam: Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Coal Fired: Kind	Coal Fired: Total	Coal Fired: Per Cent of Moisture	Total: Dry Coal Fired	Total: Combustible by Analysis	Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
601	80-30-F	.9828	.9872	0	.98728	Bituminous	2656	1.12	2626	2467	159
602	80-35-F	.9814	.9868	0	.98670	"	3553	1.30	3507	3303	204
603	80-45-F	.9806	.9859	0	.98633	"	4180	.91	4142	3836	306
604	80-55-F	.9811	.9875	0	.98660	"	6281	.90	6175	5829	346
605	160-35-F	.9809	.9805	0	.98636	"	3867	1.22	3820	3589	231
606	160-45-F	.9820	.9882	0	.98715	"	7484	1.08	7403	6941	461
607	160-55-F	.9817	.9898	0	.98695	"	9879	1.08	9773	8992	781
609	240-50-F	.9819	.9884	0	.98709	"	9013	1.20	8905	8380	525
610	240-53-F	.9626	.9824	0	.97344	"	7192	1.01	7120	6614	506
611	240-53-F	.9796	.9903	0	.98547	"	11507	.92	11401	10717	684
613	280-50-F	.9808	.9903	0	.98643	"	7744	1.14	7656	7225	431

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs — Total: Cinders Collected in Smoke Box	Coal, Sparks and Ash, Lbs — Total: Sparks Discharged From Stack	Coal, Sparks and Ash, Lbs — Total: Cinders and Sparks	Analysis of Coal — Per Cent: Fixed Carbon	Analysis of Coal — Per Cent: Volatile Matter	Analysis of Coal — Per Cent: Moisture	Analysis of Coal — Per Cent: Ash	Analysis of Coal — Per Cent: Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
601	80-30-F	62	26	88	76.13	16.77	1.12	5.98	1.05		
602	80-35-F	16	0	16	75.73	17.23	1.30	5.74	1.00		
603	80-45-F	38	55	93	74.79	16.99	.91	7.31	.83		
604	80-55-F	47	265	312	77.23	16.32	.90	5.55	.79		
605	160-35-F	47	76	123	75.91	16.90	1.22	5.97	.98		
606	160-45-F	23	180	203	75.27	17.49	1.08	6.16	1.35		
607	160-55-F	36	266	302	73.51	17.51	1.08	7.90	2.85		
609	240-50-F	151	371	522	75.51	17.47	1.20	5.82	1.09		
610	240-53-F	172	440	612	74.94	17.02	1.01	7.03	1.48		
611	240-53-F	24	357	381	76.76	16.38	.92	5.94	.88		
613	280-50-F	146	408	554	76.74	16.56	1.14	5.56	.72		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B. T. U.: Of Dry Coal	Calorific Value Per Lb. of Fuel, B. T. U.: Of Combustible	Calorific Value Per Lb. of Fuel, B. T. U.: Of Cinders	Calorific Value Per Lb. of Fuel, B. T. U.: Of Sparks		Analysis of Smoke Box Gases — Per Cent: Oxygen O	Analysis of Smoke Box Gases — Per Cent: Carbon Monoxide CO	Analysis of Smoke Box Gases — Per Cent: Carbon Dioxide CO_2	Analysis of Smoke Box Gases — Per Cent: Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
601	80-30-F	14992	15958	11305	10452		8.50	0	10.63	80.87		
602	80-35-F	15128	16062	11519	10665		6.87	0	11.73	81.40		
603	80-45-F	14853	16036	12165	11945		6.20	.13	11.93	81.74		
604	80-55-F	15067	15961	12585	11732		7.30	0	11.50	81.20		
605	160-35-F	15008	15973	11092	10452		7.60	.10	11.55	80.75		
606	160-45-F	14986	15982	11305	10452		5.70	.07	12.73	81.50		
607	160-55-F	14663	15985	11092	10452		5.13	.17	12.70	82.00		
609	240-50-F	15005	15944	12585	12159		5.20	.53	11.97	82.30		
610	240-53-F	14868	16005	13438	13225		2.75	1.15	13.45	82.65		
611	240-53-F	15070	16031	13225	13012		5.27	.50	12.07	82.16		
613	280-50-F	14996	15889	13225	12799		2.13	.40	14.13	83.34		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 585.

Atchison, Topeka & Santa Fe Railway System.

Test Number	Laboratory Designation	Water, in Pounds						Dynamometer		
			Lost					Drawbar Pull in Pounds		
		Delivered to Injectors	From Boiler	From Injectors	From	Total	Delivered to Boiler and Presumably Evaporated	Average	Maximum	Minimum
		259	260	261	262	263	264	265	266	267
601	80-30-F	26875		0		0	26875	6058	6400	5638
602	80-35-F	32808		0		0	32808	7847	8008	7522
603	80-45-F	39353		40		40	39313	9998	10507	9653
604	80-55-F	51838		0		0	51838	12815	13150	12150
605	160-35-F	32996		0		0	32996	7538	7861	6791
606	160-45-F	62574		0		0	62574	8706	8902	8251
607	160-55-F	77771		0		0	77771	11119	11530	10580
609	240-50-F	58139		0		0	58139	6808	7811	6153
610	240-53-F	41027		52		52	40975	8679	9351	8228
611	240-53-F	68251		0		0	68251	8444	8908	8202
613	280-50-F	46657		0		0	46657	5120	6060	3675

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Cut-off, Per Cent. of Stroke								Release, Per Cent. of Stroke			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
601	80-30-F	31.4	25.4	28.3	21.8	32.2	29.7	29.3	30.3	61.4	56.4	56.9	47.8
602	80-35-F	37.1	27.9	33.8	25.0	36.8	32.8	32.8	33.2	65.3	60.3	62.4	57.9
603	80-45-F	44.4	36.2	39.5	30.2	44.1	39.5	40.0	40.8	70.1	62.3	64.7	52.2
604	80-55-F	60.0	49.1	56.9	45.8	60.1	55.5	56.2	55.8	78.6	68.5	76.5	63.8
605	160-35-F	42.3	35.2	35.3	31.4	40.9	37.6	33.8	33.3	70.1	61.8	64.6	58.0
606	160-45-F	49.2	42.1	41.8	38.9	45.9	42.2	39.1	39.8	76.5	64.9	68.3	61.7
607	160-55-F	59.1	47.3	55.6	39.8	54.8	51.1	48.7	50.4	83.0	69.3	76.5	62.3
609	240-50-F	53.6	43.6	50.5	37.9	51.7	48.9	48.8	44.5	78.6	67.4	77.8	62.9
610	240-53-F	62.4	49.5	56.5	43.2	59.3	54.4	52.5	55.6	85.0	69.9	82.8	64.5
611	240-53-F	59.6	47.5	56.1	41.8	56.9	54.4	52.8	52.2	84.6	68.8	81.8	62.0
613	280-50-F	52.2	46.5	52.8	39.2	53.6	48.0	49.2	47.7	66.2	65.8	71.8	56.2

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
601	80-30-F	54.2	51.3	51.3	51.5	30.9	24.6	26.3	22.2	28.1	25.8	26.9	28.9
602	80-35-F	59.3	55.9	54.9	55.2	31.9	20.1	28.6	20.7	25.1	23.3	25.2	25.5
603	80-45-F	64.4	59.6	59.5	57.4	27.7	16.5	21.9	18.6	21.0	19.3	20.7	22.5
604	80-55-F	74.9	72.4	70.6	70.1	17.9	10.5	19.2	11.1	24.9	20.8	24.7	23.9
605	160-35-F	64.6	62.0	59.8	57.4	27.5	20.4	32.0	19.2	27.3	26.3	26.4	27.7
606	160-45-F	66.9	65.3	62.2	60.8	26.8	22.8	30.0	17.8	25.7	25.5	26.3	28.0
607	160-55-F	72.7	70.5	68.7	69.3	29.7	16.7	21.8	22.3	22.6	21.7	23.6	28.1
609	240-50-F	71.0	69.7	68.8	67.7	33.3	18.9	29.8	20.9	25.8	23.8	23.8	25.2
610	240-53-F	76.9	72.4	71.4	73.7	31.8	17.0	26.3	18.4	19.4	20.8	21.4	23.7
611	240-53-F	78.5	71.8	71.9	71.4	32.7	19.8	31.1	20.8	21.5	20.0	22.0	22.0
613	280-50-F	70.6	65.7	68.7	67.3	33.6	17.7	32.0	21.2	25.0	20.8	25.2	25.8

Test Number	Laboratory Designation	Pressure from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
601	80-30-F	213.0	216.1	216.3	212.4	71.3	64.6	69.5	64.5	1.2050
602	80-35-F	212.4	215.1	211.4	208.1	78.2	72.1	82.6	75.8	1.2058
603	80-45-F	219.9	220.6	218.3	222.5	79.6	72.7	77.9	72.4	1.2100
604	80-55-F	225.6	225.0	227.1	229.4	89.2	81.7	80.5	82.9	1.2150
605	160-35-F	210.4	212.2	202.1	212.3	85.9	78.9	84.3	82.4	1.2068
606	160-45-F	227.2	228.9	228.5	217.8	83.7	78.6	81.7	81.6	1.2086
607	160-55-F	224.8	234.4	225.7	243.5	88.1	80.5	85.1	80.7	1.2077
609	240-50-F	218.5	235.7	216.5	231.1	81.4	77.5	82.1	76.8	1.2083
610	240-53-F	205.4	208.5	195.3	209.2	79.3	77.5	79.9	76.9	1.2101
611	240-53-F	219.8	224.3	212.4	227.3	84.7	81.6	83.8	81.7	1.2180
613	280-50-F	217.8	223.5	212.5	220.8	84.4	81.3	84.3	82.5	1.2210

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

Atchison, Topeka & Santa Fe Railway System.

Test Number	Laboratory Designation	Pressures from Indicator Cards								
		Steam Chest Pressures, Pounds Per Square Inch					Pressures at Cut-off, Pounds Per Square Inch			
		High Pressure		Low Pressure			High Pressure Cylinder			
							Right Side		Left Side	
		Right Side	Left Side	Right Side	Left Side		Head End	Crank End	Head End	Crank End
		301	302	303	304	305	306	307	308	309
601	80-30-F	211.8	216.0				183.1	194.0	181.8	178.2
602	80-35-F	212.8	217.6				187.9	194.8	188.4	184.5
603	80-45-F	220.6	——				188.5	186.3	181.3	182.0
604	80-55-F	223.8	——				193.7	195.0	196.2	188.8
605	160-35-F	221.2	219.2				173.4	178.0	169.5	172.7
606	160-45-F	219.1	——				164.8	168.4	157.9	161.5
607	160-55-F	221.3	——				180.5	176.2	177.2	170.2
609	240-50-F	219.4	——				157.2	165.0	150.0	160.1
610	240-53-F	208.3	——				150.6	162.0	148.8	153.1
611	240-53-F	217.4	——				166.4	174.5	161.9	169.3
613	280-50-F	——	——				151.0	162.2	144.0	151.8

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Cut-off, Pounds Per Square Inch				Pressures at Release, Pounds Per Square Inch							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
601	80-30-F	42.2	40.3	39.4	38.6	108.0	108.0	103.1	100.8	20.2	18.1	16.7	17.5
602	80-35-F	48.0	43.4	52.3	45.8	117.5	123.2	123.9	116.9	24.3	21.1	25.4	22.2
603	80-45-F	45.1	43.4	43.6	40.2	126.8	126.1	128.2	121.1	25.1	24.4	24.9	23.9
604	80-55-F	49.1	46.4	47.3	46.7	153.9	146.1	152.7	145.4	35.4	32.1	33.3	35.0
605	160-35-F	42.9	41.8	43.3	43.3	112.8	118.9	105.5	111.6	22.1	20.8	19.0	21.3
606	160-45-F	44.7	42.5	40.7	42.6	110.2	118.2	108.8	112.4	24.9	24.0	20.4	22.3
607	160-55-F	47.4	43.6	45.8	44.3	132.0	127.6	132.1	120.7	31.5	29.3	27.3	28.8
609	240-50-F	41.2	37.5	37.3	37.8	112.4	115.4	108.0	110.0	25.6	22.9	22.3	21.6
610	240-53-F	39.5	38.3	38.3	36.4	113.4	123.6	109.2	112.4	26.5	26.0	24.1	24.8
611	240-53-F	42.5	39.8	40.4	38.8	119.5	128.0	117.2	124.0	30.3	28.0	25.9	26.1
613	280-50-F	37.0	34.5	33.5	35.2	123.8	113.3	109.5	113.2	24.4	18.3	20.2	21.3

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

Atchison, Topeka & Santa Fè Railway System.

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Beginning of Compression, Pounds Per Square Inch								Least Back Pressure, Pounds Per Square Inch			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
601	80–30–F	88.9	85.3	96.0	83.2	4.1	4.0	4.2	4.1	54.8	58.3	55.0	57.5
602	80–35–F	92.3	92.2	95.7	91.2	4.0	4.0	4.0	4.1	61.9	61.1	69.1	66.1
603	80–45–F	93.9	95.1	99.8	90.7	4.5	5.3	5.1	4.6	58.8	61.8	62.4	60.7
604	80–55–F	102.9	104.1	101.5	106.9	1.8	1.9	1.5	2.9	62.4	62.0	63.2	61.7
605	160–35–F	101.8	96.2	100.5	96.8	6.1	5.6	6.3	4.7	66.9	69.3	68.1	70.2
606	160–45–F	102.7	89.2	104.9	98.6	6.2	5.7	6.4	6.4	66.6	71.3	69.3	70.4
607	160–55–F	86.1	80.8	109.4	82.1	6.3	6.0	6.6	7.1	65.5	67.3	68.5	66.7
609	240–50–F	89.0	89.5	103.8	90.4	12.8	12.7	13.0	12.5	70.6	74.5	72.2	71.5
610	240–53–F	83.4	85.9	97.1	83.5	16.0	16.8	16.1	14.8	69.3	72.6	70.7	69.8
611	240–53–F	87.6	89.0	96.1	89.2	15.3	16.8	15.8	15.2	72.5	75.9	74.9	73.9
613	280–50–F	92.0	93.5	103.2	91.0	17.2	18.3	15.5	14.7	71.2	78.5	77.3	75.7

Test Number	Laboratory Designation	Pressures from Indicator Cards				Boiler					
		Least Back Pressure, Pounds Per Square Inch				Dry Coal Fired Pounds		Evaporation, Pounds			
		Low Pressure Cylinder						Steam Per Hour			
		Right Side		Left Side							
		Head End	Crank End	Head End	Crank End	Per Hour	Per Hour Per Square Foot of Grate Surface	Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
601	80–30–F	0	0	0	0	875	18.10	8958	8844	3.048	10.10
602	80–35–F	0	0	0	0	1169	24.17	10936	10791	3.719	9.23
603	80–45–F	0	0	0	0	1381	28.50	13104	12924	4.454	9.36
604	80–55–F	1.2	1.6	.3	2.1	2058	42.56	17279	17047	5.874	8.28
605	160–35–F	1.3	.9	.1	1.0	2055	42.49	17748	17506	6.033	8.52
606	160–45–F	1.9	1.8	.2	2.7	2468	51.03	20858	20590	7.095	8.34
607	160–55–F	3.4	3.6	3.2	4.7	3258	67.36	25924	25585	8.816	7.86
609	240–50–F	5.5	5.3	4.1	5.7	4452	92.06	29070	28693	9.887	6.45
610	240–53–F	7.6	9.0	6.3	8.1	5831	120.57	33563	32672	11.258	5.60
611	240–53–F	8.4	8.7	6.4	8.4	5701	117.87	34126	33630	11.589	5.90
613	280–50–F	6.4	6.3	4.8	6.5	5104	105.52	31102	30681	10.572	6.01

For steam lost from boiler and not delivered to engines, see item 216.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Boiler: Equiv't Evap'n: Per Hour, Per Sq. Ft. of Heat. Surface	Boiler: Equiv't Evap'n: Per Pound of Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Dry Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch, High Pressure Cylinder: Right Side Head End	Right Side Crank End	Left Side Head End	Left Side Crank End
		344	345	346	347	348	349	350	351	352	353	354
601	80-30-F	10656	3.67	12.04	12.17	12.96	308.9	78.43	51.9	57.7	41.6	43.9
602	80-35-F	13012	4.48	10.98	11.13	11.82	377.2	71.06	59.9	68.8	52.9	57.7
603	80-45-F	15638	5.39	11.22	11.33	12.23	453.3	73.65	76.8	77.2	70.4	68.0
604	80-55-F	20713	7.14	9.97	10.06	10.66	600.4	64.50	103.4	98.5	99.3	91.0
605	160-35-F	21128	7.28	10.16	10.28	10.92	612.4	66.16	54.6	58.4	37.2	53.5
606	160-45-F	24885	8.58	9.98	10.09	10.76	721.3	64.99	60.3	65.5	46.4	59.0
607	160-55-F	30900	10.65	9.38	9.49	10.31	895.7	62.48	81.4	81.5	76.3	70.9
609	240-50-F	34668	11.95	7.69	7.79	8.27	1004.7	50.12	61.4	65.0	52.8	55.9
610	240-53-F	39539	13.62	6.71	6.78	7.30	1145.9	44.05	66.3	71.6	62.1	62.3
611	240-53-F	40964	14.11	7.12	7.19	7.65	1187.2	46.05	68.7	73.1	63.3	66.0
613	280-50-F	37463	12.91	7.26	7.34	7.78	1085.8	47.27	53.6	65.4	46.2	53.0

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square inch, Low Pressure Cylinder: Right Side Head End	Right Side Crank End	Left Side Head End	Left Side Crank End	Receiver Pressure: Right Side	Receiver Pressure: Left Side	Number of Expansions: Right Side Head End	Right Side Crank End	Left Side Head End	Left Side Crank End
		355	356	357	358	359	360	361	362	363	364
601	80-30-F	19.8	17.2	16.0	16.8			3.41	3.72	3.45	4.06
602	80-35-F	27.2	24.1	26.3	24.5			3.32	3.80	3.28	4.01
603	80-45-F	32.1	29.1	31.7	27.5			3.15	3.42	3.17	3.71
604	80-55-F	46.4	42.5	43.9	43.1			2.90	3.31	2.85	3.38
605	160-35-F	25.5	25.5	23.7	24.2			3.27	3.61	3.44	3.62
606	160-45-F	31.8	29.1	25.8	26.4			2.83	3.36	3.18	3.82
607	160-55-F	38.3	35.4	34.3	34.7			2.85	3.32	2.83	3.69
609	240-50-F	27.4	25.4	24.5	23.3			3.00	3.48	3.04	3.73
610	240-53-F	30.6	26.6	26.1	25.0			2.88	3.29	2.89	3.69
611	240-53-F	30.6	28.2	28.8	27.0			2.86	3.36	2.93	3.66
613	280-50-F	22.9	21.3	20.4	20.9			3.05	3.15	2.94	3.63

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
601	80-30-F	48.4	51.3	38.8	39.1	51.0	43.7	41.3	42.8	99·7	77.8	94.7	84.0
602	80-35-F	55.9	61.2	49.3	51.3	70.1	61.2	67.9	62.2	117.0	100.6	131.3	130.1
603	80-45-F	71.6	68.6	65.6	56.0	82.8	73.9	82.0	69.9	140.2	121.7	156.7	151.9
604	80-55-F	96.4	87.5	92.7	80.9	119.9	108.0	113.5	109.4	183.9	173.6	227.9	223.0
605	160-35-F	101.8	103.8	69.4	95.1	131.9	129.6	122.6	122.9	205.5	164.5	261.5	245.6
606	160-45-F	112.4	116.5	86.5	104.9	164.5	147.7	133.3	134.1	228.9	191.4	312.2	267.4
607	160-55-F	151.8	144.8	142.3	126.2	198.0	179.7	177.1	176.2	296.6	268.5	377.7	353.3
609	240-50-F	171.6	173.3	147.7	149.0	212.4	193.3	189.9	177.5	344.9	296.7	405.6	367.4
610	240-53 F	185.3	190.9	173.7	166.8	237.4	202.7	202.6	190.5	376.1	340.0	440.2	393.1
611	240-53-F	192.2	194.9	177.2	176.0	236.9	215.1	223.1	206.0	387.1	353.2	452.0	429.1
613	280-50-F	174.7	208.2	150.9	165.1	206.9	189.0	184.4	185.5	378.0	315.9	395.9	369.9

Test Number	Laboratory Designation	Engines						Locomotive			
		Division of Power			Consumed Per I. H. P., Hour			Dynamometer Horse Power	Pounds Per D. H. P., Hour		B. T. U. Per D. H. P. Hour
		Total		Total I. H. P.							
		Right Side	Left Side		Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.		Of Dry Coal	Of Dry Steam	
		377	378	379	380	381	382	383	384	385	386
601	80-30-F	194.4	161.8	356.2	2.34	23.67	35081	303.5	2.75	27.77	41159
602	80-35-F	248.3	230.7	479.0	2.35	21.67	35500	393.2	2.86	26.39	43243
603	80-45-F	296.9	273.5	570.4	2.34	21.91	34731	501.0	2.66	24.94	39537
604	80-55-F	411.8	396.6	808.4	2.48	20.56	37394	642.3	3.12	25.88	47071
605	160-35-F	467.0	410.1	877.1	2.28	19.44	34239	755.0	2.65	22.59	39772
606	160-45-F	541.1	458.8	999.9	2.42	20.17	36219	872.7	2.77	23.11	41499
607	160-55-F	674.3	621.8	1296.1	2.47	19·41	36231	1114.4	2.87	22.58	42133
609	240-50-F	750.5	664.2	1414.6	3.10	19.99	46531	1022.3	4.29	27.66	64390
610	240-53-F	816.3	733.1	1549.4	3.72	20.82	55238	1304.6	4.41	24.73	65600
611	240-53-F	839.2	782.3	1621.5	3.47	20.48	52291	1269.8	4.43	26.15	67768
613	280-50-F	773.8	685.8	1459.7	3.45	20.73	51720	898.0	5.60	33.70	84060

For Maximum Indicated Horse Power, see item 403.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.

Atchison, Topeka & Santa Fe Railway System.

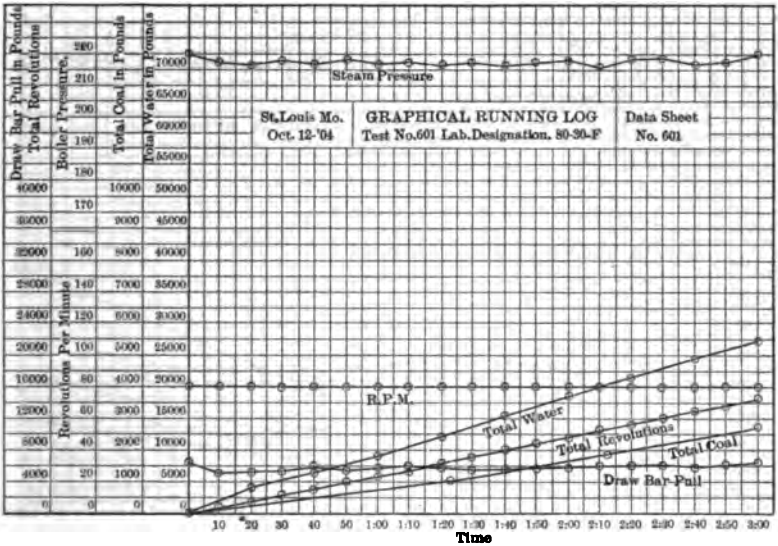
Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	I. H. P. Per Square Foot of: Heating Surface	Grate Surface	D. H. P. Per Square Foot of: Heating Surface	Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
601	80–30–F	1.39	14.02	20783	.1228	7.37	.1046	6.28	7143	52.69		1057
602	80–35–F	1.44	13.83	21841	.1651	9.91	.1355	8.13	9605	85.77		1720
603	80–45–F	1.35	12.61	19997	.1966	11.80	.1727	10.36	11437	69.37		1391
604	80–55–F	1.58	13.07	23772	.2785	16.71	.2213	13.28	16207	166.10		3309
605	160–35–F	1.36	11.54	20367	.3022	18.14	.2602	15.61	8796	122.06		1224
606	160–45–F	1.40	11.67	20960	.3446	20.68	.3007	18.05	10024	127.15		1275
607	160–55–F	1.45	11.40	21280	.4466	26.80	.3841	23.05	12994	181.69		1829
609	240–50–F	2.17	13.97	32523	.4875	29.25	.3523	21.14	9459	392.31		2623
610	240–53–F	2.33	13.07	34668	.5339	32.04	.4496	26.98	10354	244.79		1636
611	240–53–F	2.24	13.21	33729	.5587	33.53	.4376	26.26	10838	351.66		2350
613	280–50–F	2.88	17.02	42455	.5030	30.18	.3095	18.57	8362	561.65		3218

Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
601	80–30–F	85.22	6.18	494.9	7.13	601	407.2				10–12–04
602	80–35–F	82.10	5.89	403.8	5.82	779	499.0				10–14–04
603	80–45–F	87.84	6.44	334.7	4.82	992	602.7				10–20–04
604	80–55–F	79.46	5.41	247.8	3.57	1272	813.4				10–20–04
605	160–35–F	86.08	6.40	223.4	3.22	1474	902.2				10–13–04
606	160–45–F	87.28	6.13	199.4	2.87	1728	1010.4				10–17–04
607	160–55–F	85.99	6.04	148.6	2.14	2207	1355.7				10–15–04
609	240–50–F	72.27	3.95	142.2	2.05	2024	1416.7				10–17–04
610	240–53–F	84.20	3.88	121.9	1.76	2469	1653.4				10–18–04
611	240–53–F	78.31	3.81	118.3	1.70	2514	1703.2				10–22–04
613	280–50–F	61.53	3.03	137.6	1.98	1778	1464.7				10–31–04

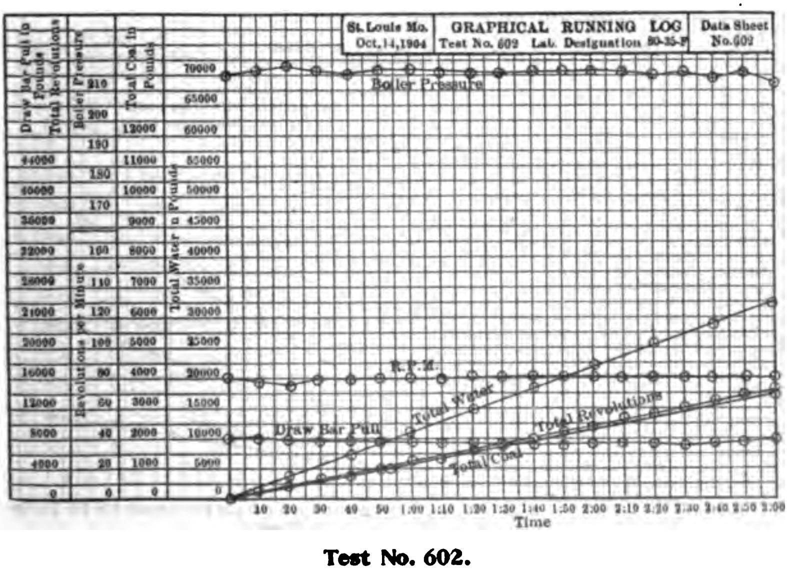
GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 535.
ATCHISON, TOPEKA & SANTA FE RAILWAY SYSTEM.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft, Front of Diaphragm, Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	208	217	220	222	338	341
601	80-30-F	3.00	80.00	18.79	26·7	FULL	217.6	210.0	.83	875	8844
602	80-35-F	3.00	80.00	18.79	31.0	"	215.7	208.1	1.18	1169	10791
603	80-45-F	3.00	80.00	18.79	37.6	"	221.0	213.4	1.50	1331	12924
604	80-55-F	3.00	80.01	18.79	53.0	"	220.4	212.0	2.62	2058	17047
605	160-35-F	1.86	160.00	37.59	36.1	"	220.6	211.4	2.30	2055	17506
606	160-45-F	3.00	160.00	37.59	43.0	"	219.2	210.4	2.84	2468	20590
607	160-55-F	3.00	160.00	37.59	50.5	"	221.9	211.8	4.54	3258	25585
609	240-50-F	2.00	239.89	56.85	46.4	"	221.2	211.5	5.59	4452	28693
610	240-53-F	1.23	239.96	56.87	52.9	"	211.4	200.3	7.27	5331	32672
611	240-53-F	2.00	240.02	56.88	51.3	"	221.0	210.3	6.59	5701	33630
613	280-50-F	1.50	280.00	65.77	47.7	"	219.5	209.3	5.58	5104	30681

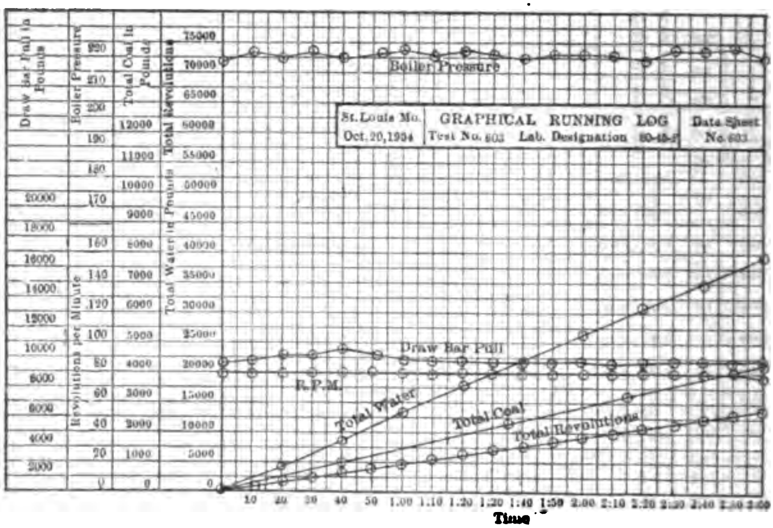
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		347	379	383	395	265	380	384	381	385	350	390
601	80-30-F	12.17	356.2	303.5	52.69	6058	2.34	2.75	23.67	27.77	78.43	6.18
602	80-35-F	11.13	479.0	393.2	85.77	7847	2.35	2.86	21.67	26.39	71.06	5.89
603	80-45-F	11.33	570.4	501.0	69.37	9998	2.34	2.66	21.91	24.94	73.65	6.44
604	80-55-F	10.06	808.4	642.3	166.10	12815	2.48	3.12	20.56	25.88	64.50	5.41
605	160-35-F	10.28	877.1	755.0	122.06	7533	2.28	2.65	19.44	22.59	66.16	6.40
606	160-45-F	10.09	999.9	872.7	127.15	8708	2.42	2.77	20.17	23.11	64.99	6.13
607	160-55-F	9.49	1296.1	1114.4	181.69	11119	2.47	2.87	19.41	22.58	62.48	6.04
609	240-50-F	7.79	1414.6	1022.3	392.31	6803	3.10	4.29	19.99	27.66	50.12	3.95
610	240-53-F	6.78	1549.4	1304.6	244.79	8679	3.72	4.41	20.82	24.73	44.05	3.88
611	240-53-F	7.19	1621.5	1269.8	351.66	8444	3.47	4.43	20.48	26.15	46.05	3.81
613	280-50-F	7.34	1459.7	898.0	561.65	5120	3.45	5.60	20.73	33.70	47.27	3.03



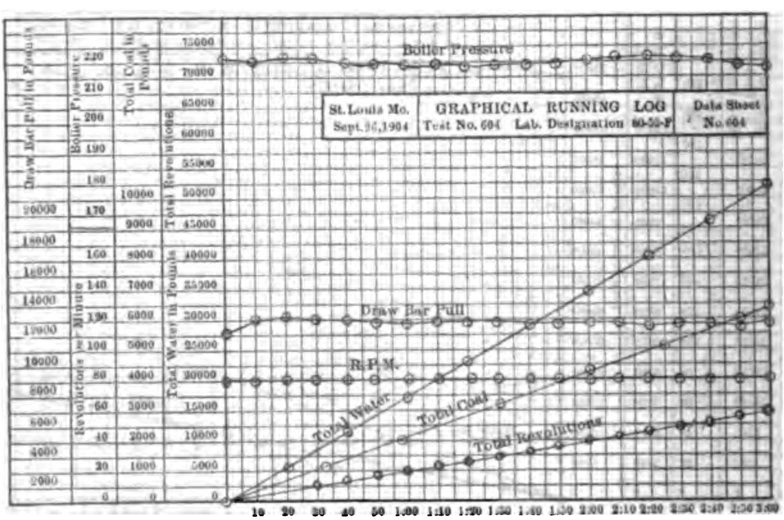
Test No. 601.



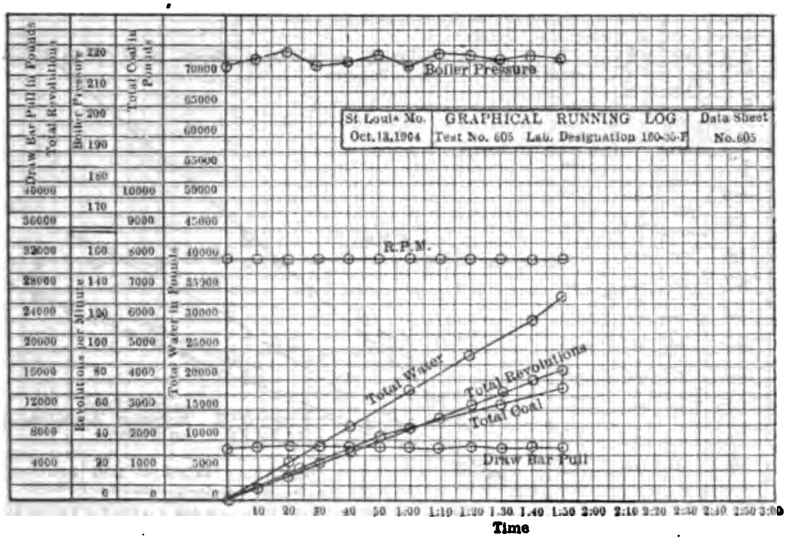
Test No. 602.



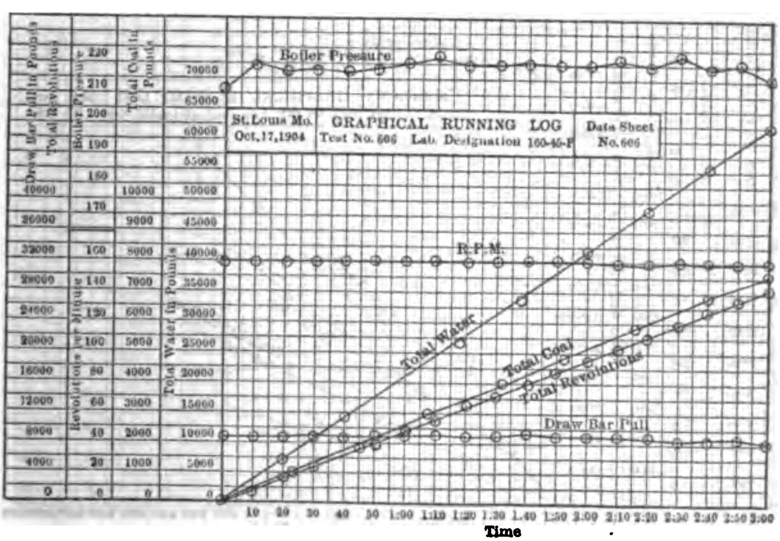
Test No. 603.



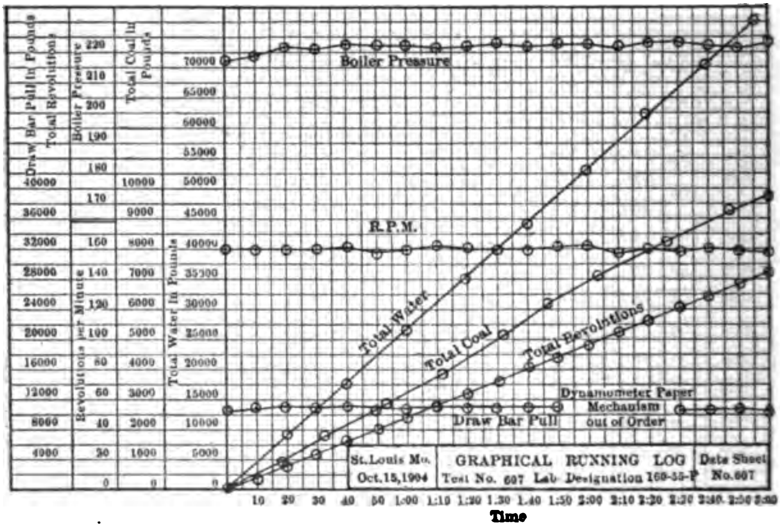
Test No. 604.



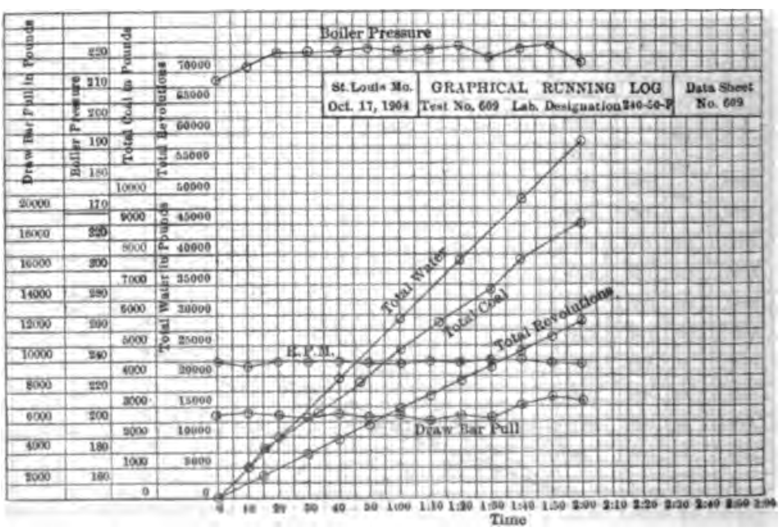
Test No. 605.



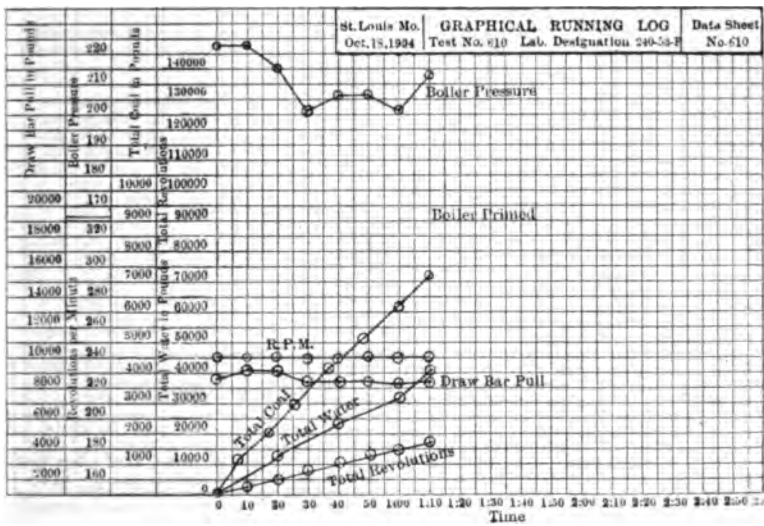
Test No. 606.



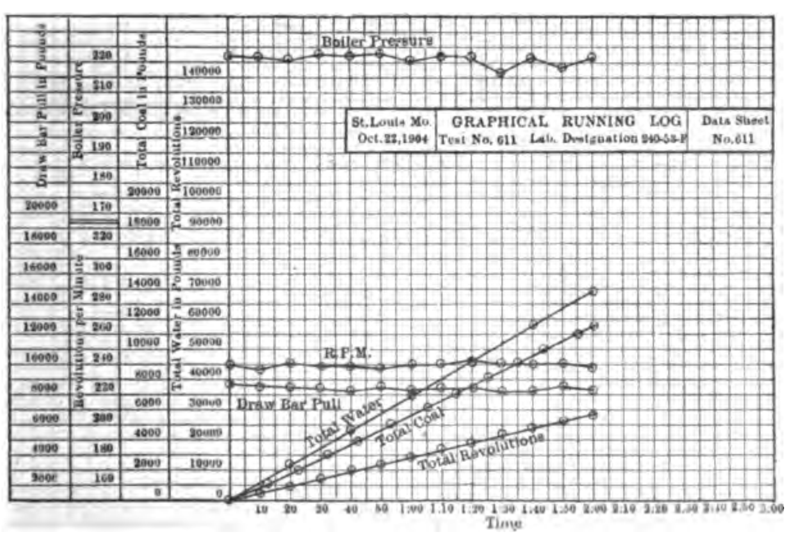
Test No. 607.



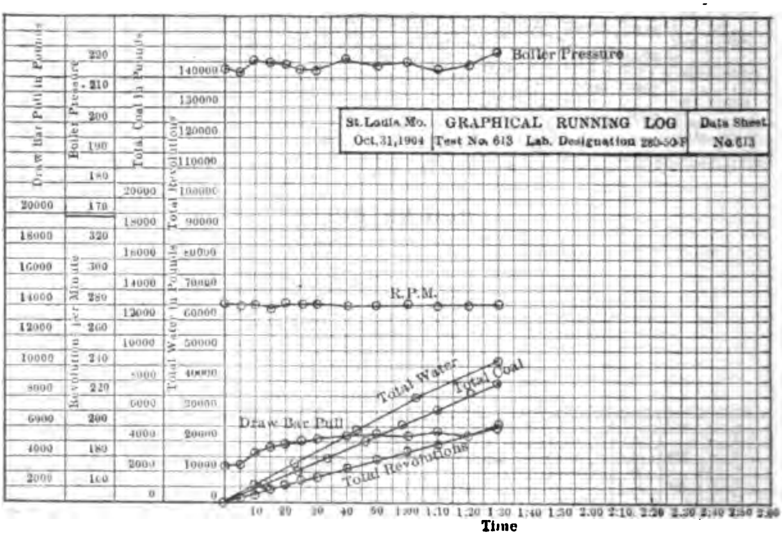
Test No. 609.



Test No. 610.

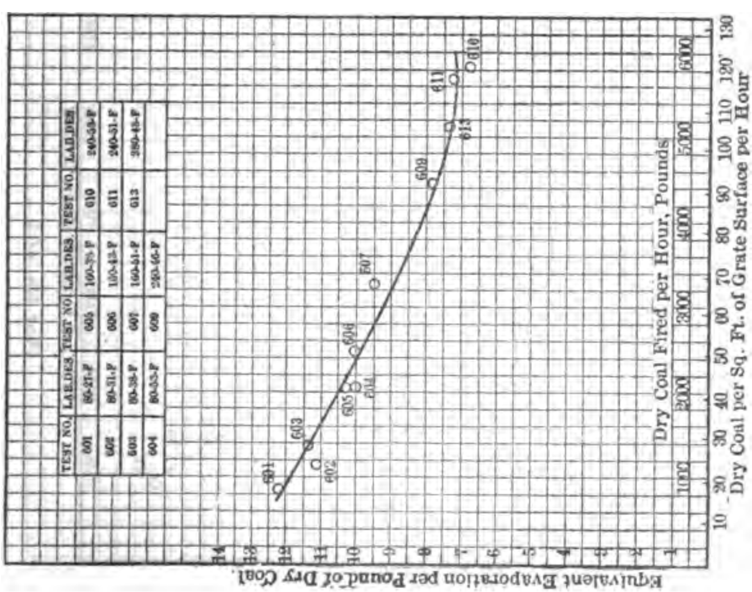


Test No. 611.

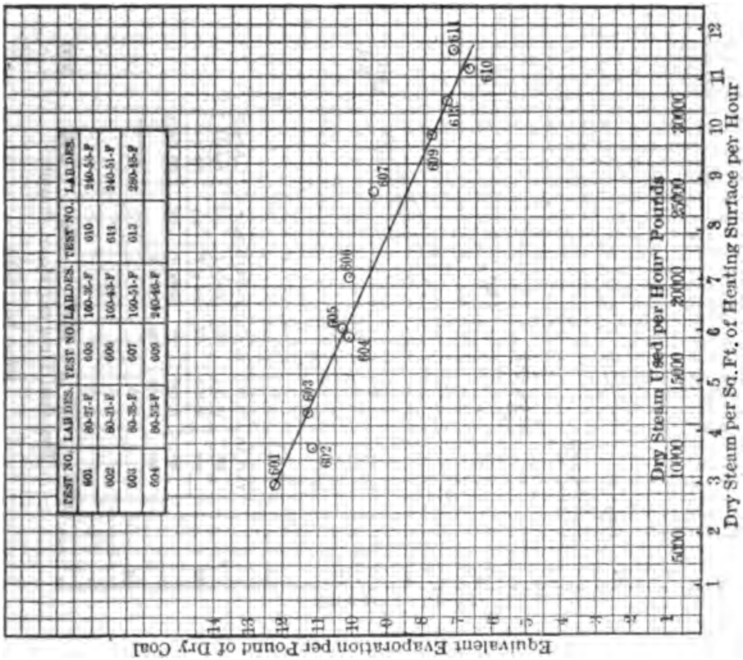


St. Louis Mo. Oct. 31, 1904
GRAPHICAL RUNNING LOG
Test No. 613 Lab. Designation 280-50-F
Data Sheet No. 613
Boiler Pressure
R.P.M.
Total Water
Total Coal
Draw Bar Pull
Total Revolutions
Draw Bar Pull in Pounds
Boiler Pressure
Revolutions per Minute
Total Coal in Pounds
Total Water in Pounds
Total Revolutions
Time

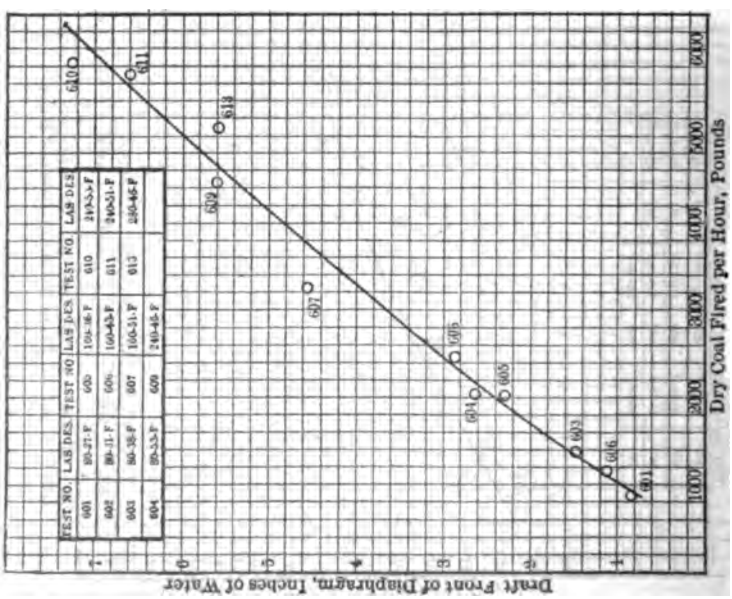
Test No. 613.



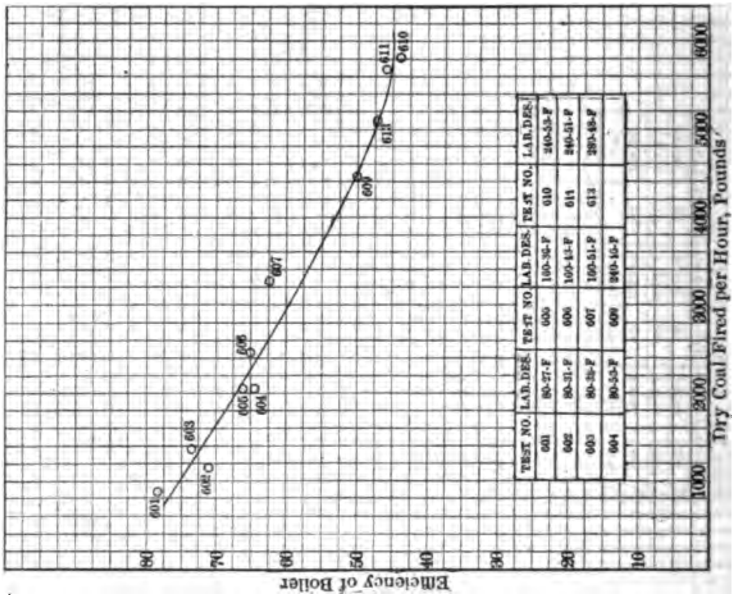
Plot No. 601.



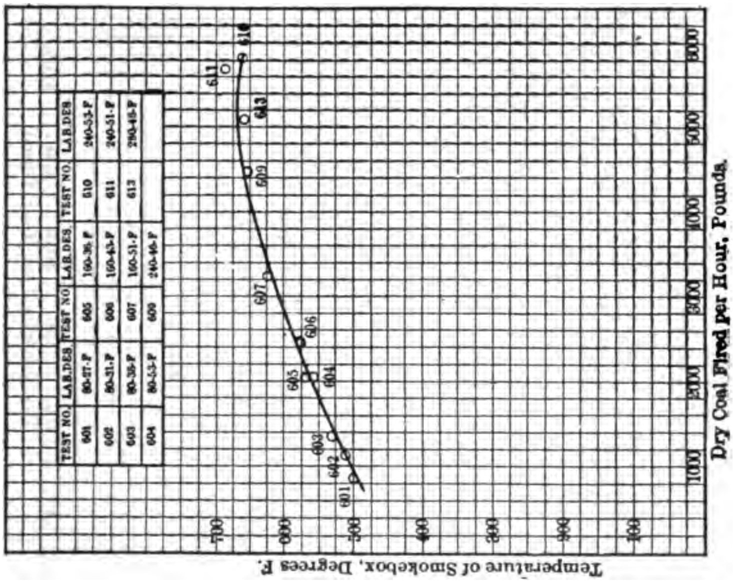
Plot No. 602.



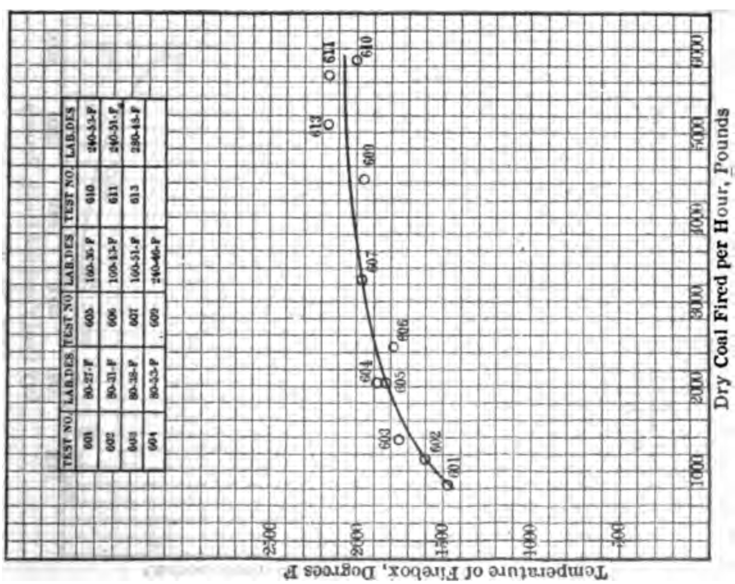
Plot No. 603.



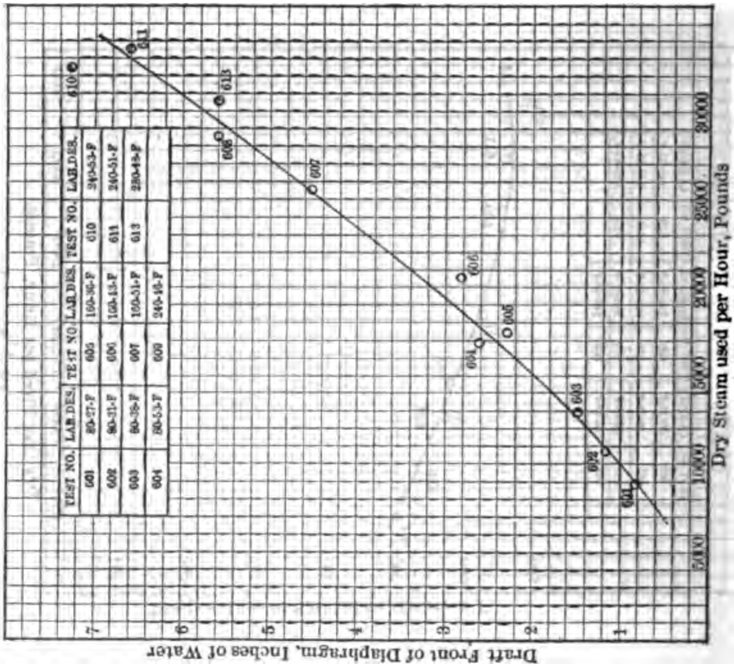
Plot No. 604.



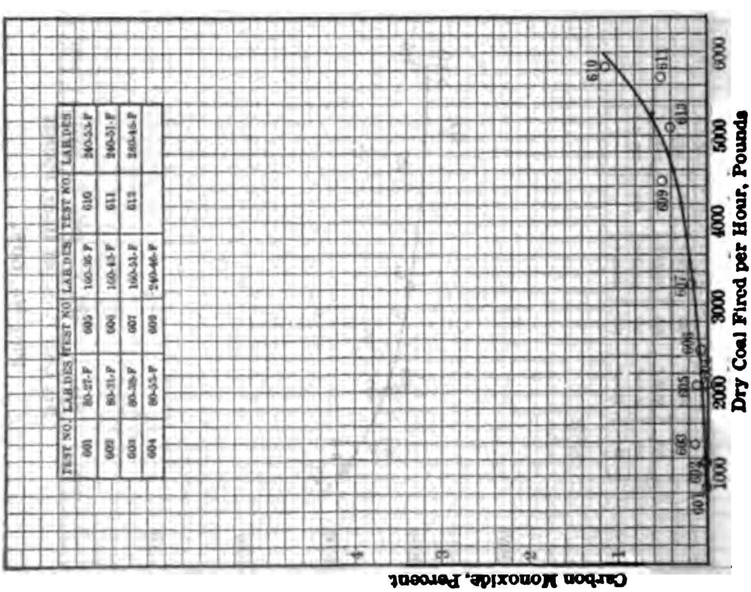
Plot No. 606.



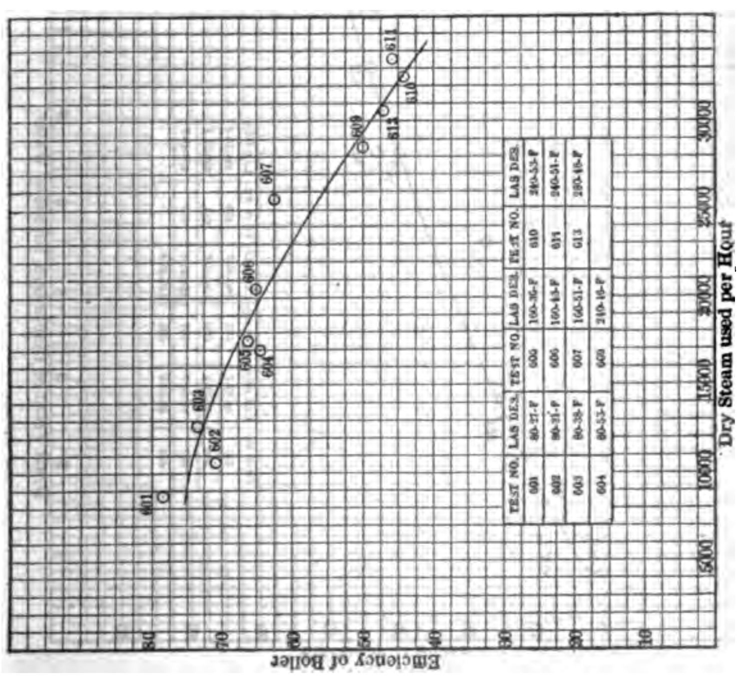
Plot No. 605.



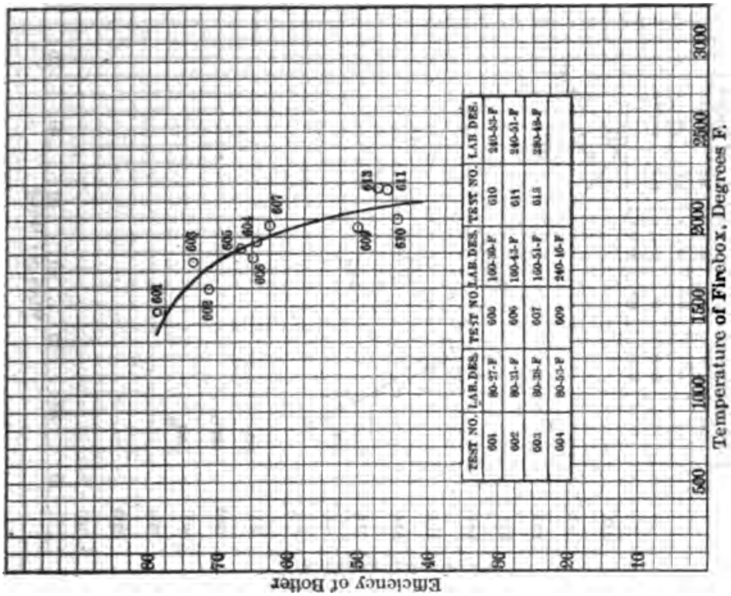
Plot No. 608.



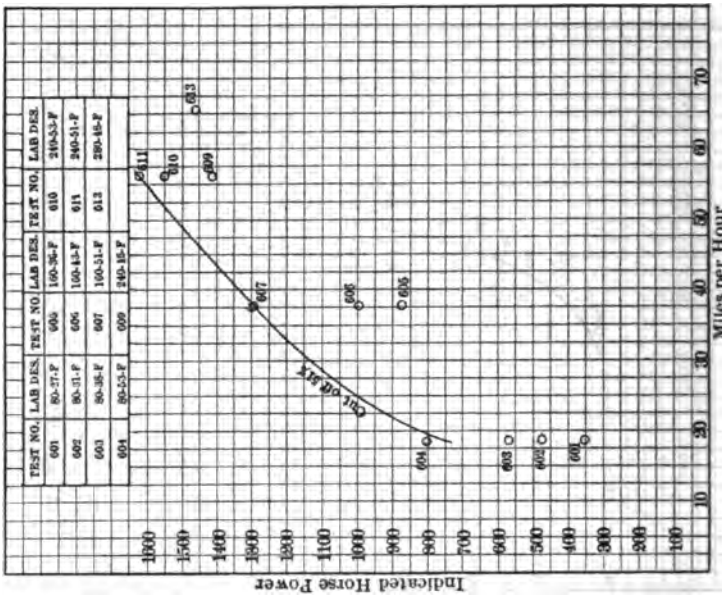
Plot No. 607.



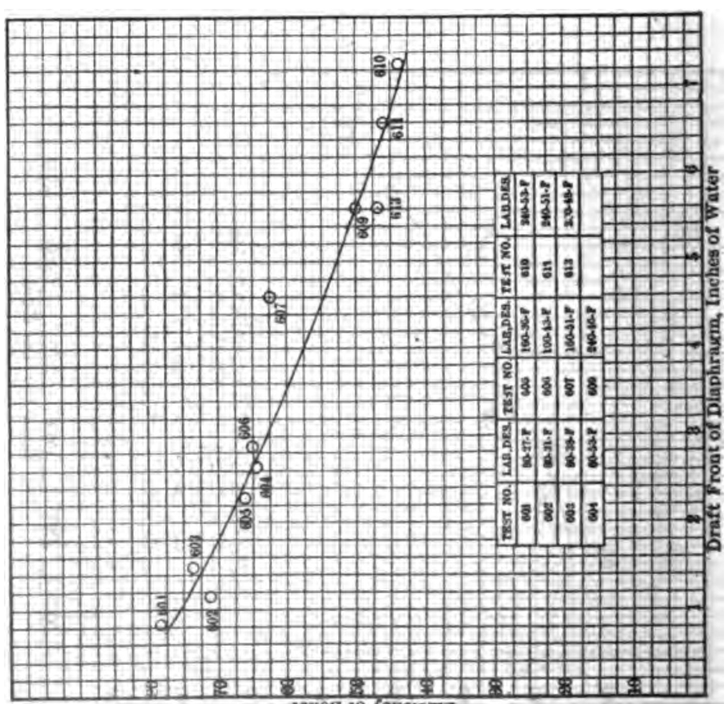
Plot No. 609.



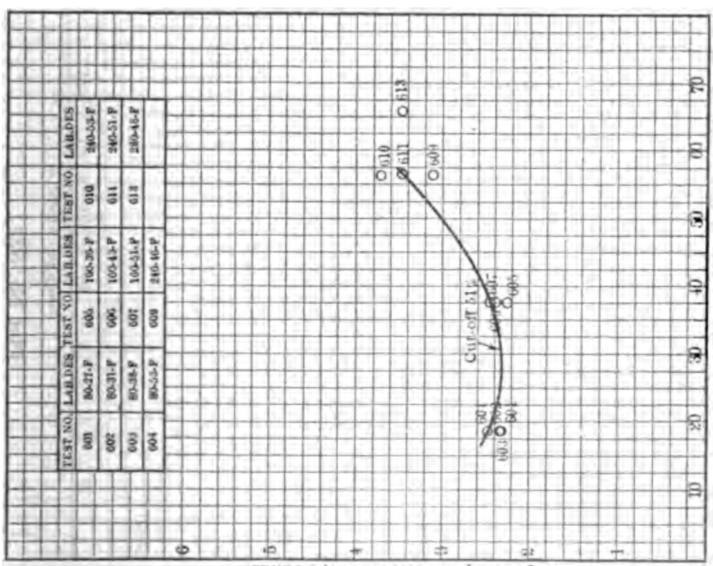
Plot No. 610.



Plot No. 620.

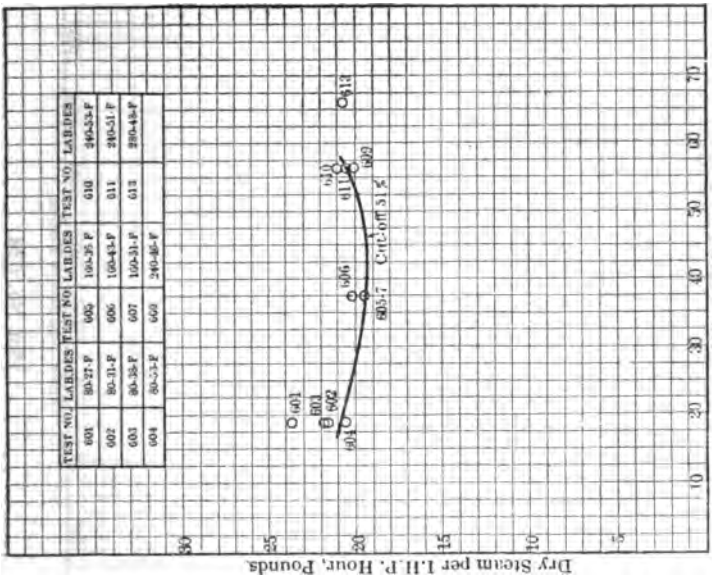


Plot No. 611.



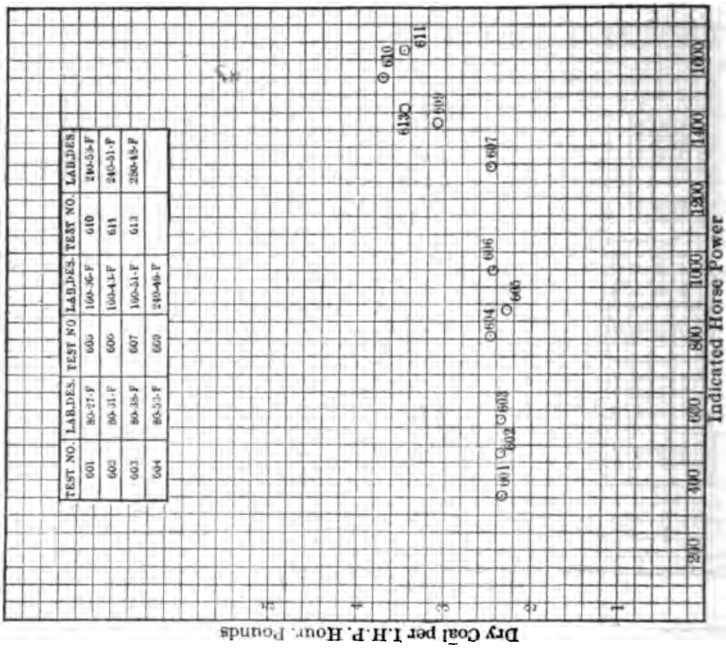
TEST NO.	LAB.DES	TEST NO.	LAB.DES	TEST NO.	LAB.DES
601	80-27-F	605	160-35-F	610	240-53-F
602	80-31-F	606	160-43-F	611	240-51-F
603	80-38-F	607	160-51-F	613	280-48-F
604	80-53-F	609	240-46-F		

Plot No. 621.

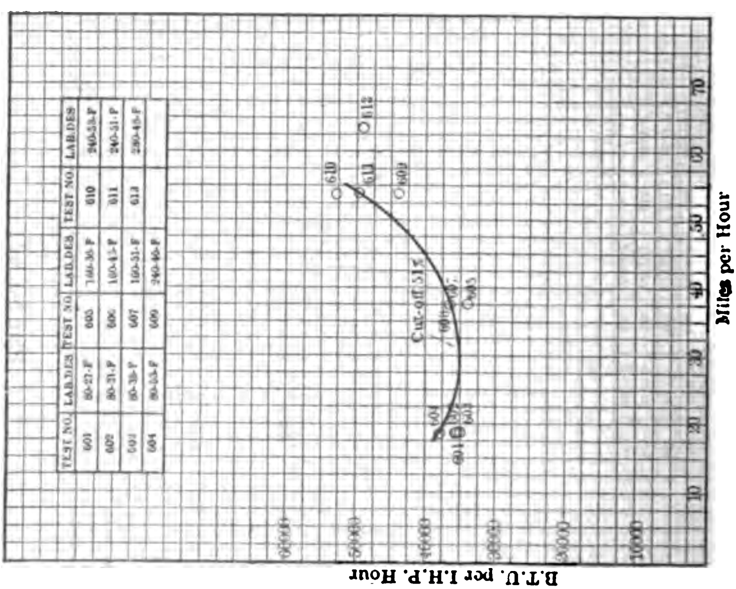


TEST NO.	LAB.DES	TEST NO.	LAB.DES	TEST NO.	LAB.DES
601	80-27-F	605	160-35-F	610	240-53-F
602	80-31-F	606	160-43-F	611	240-51-F
603	80-38-F	607	160-51-F	613	280-48-F
604	80-53-F	609	240-46-F		

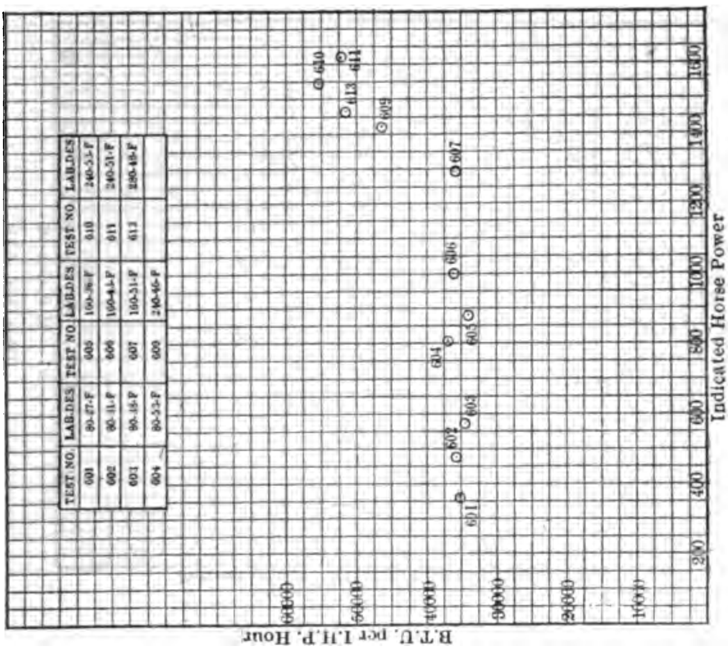
Plot No. 622.



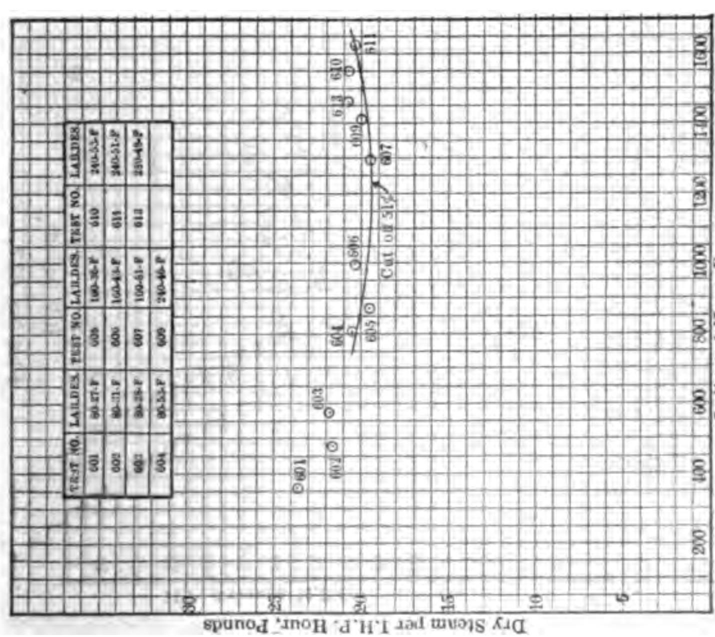
Plot No. 624.



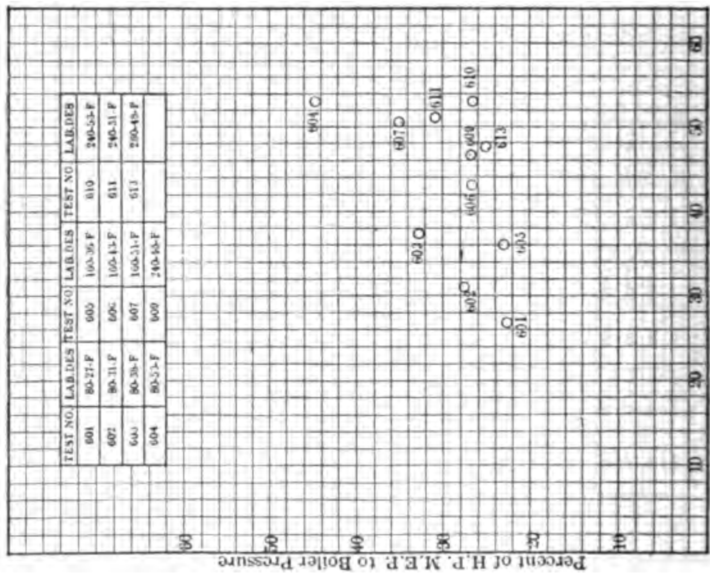
Plot No. 623.



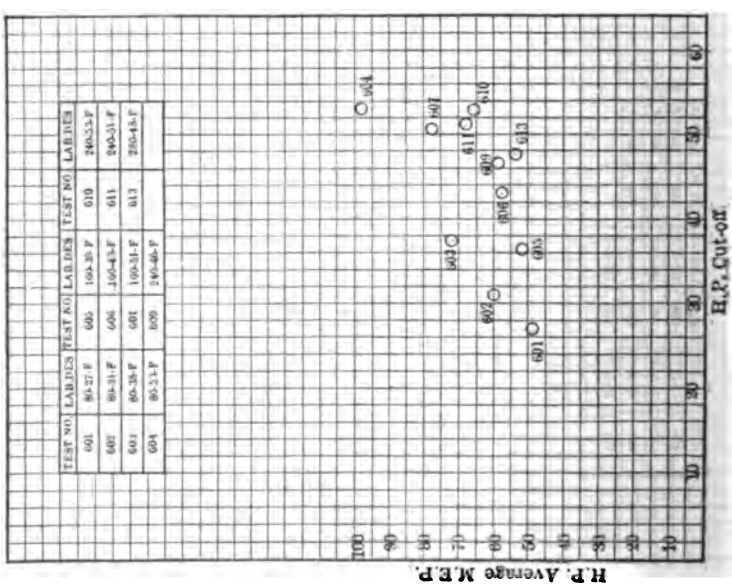
Plot No. 626.



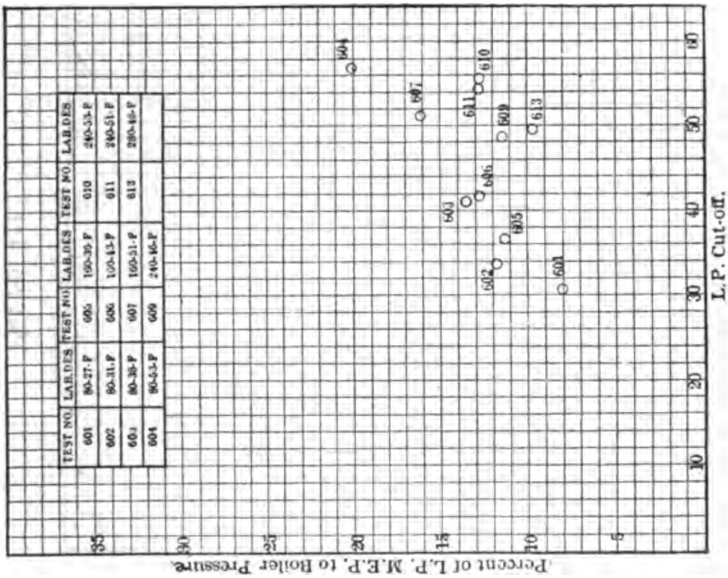
Plot No. 625.



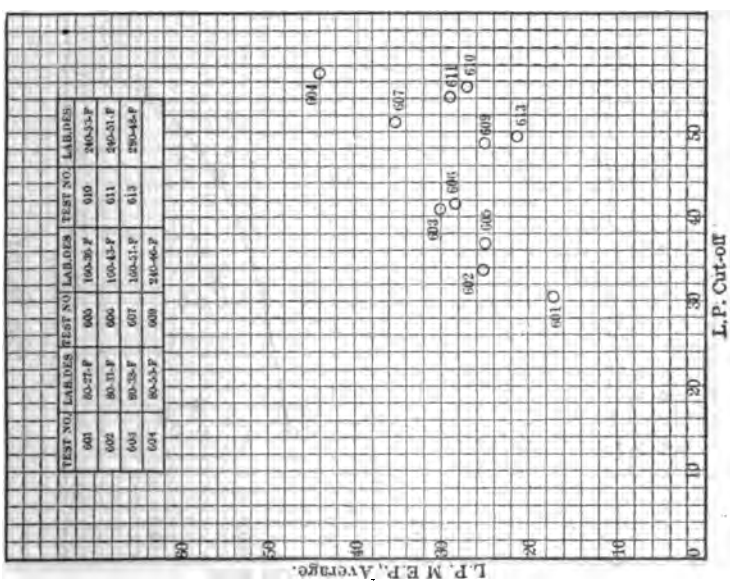
Plot No. 628.



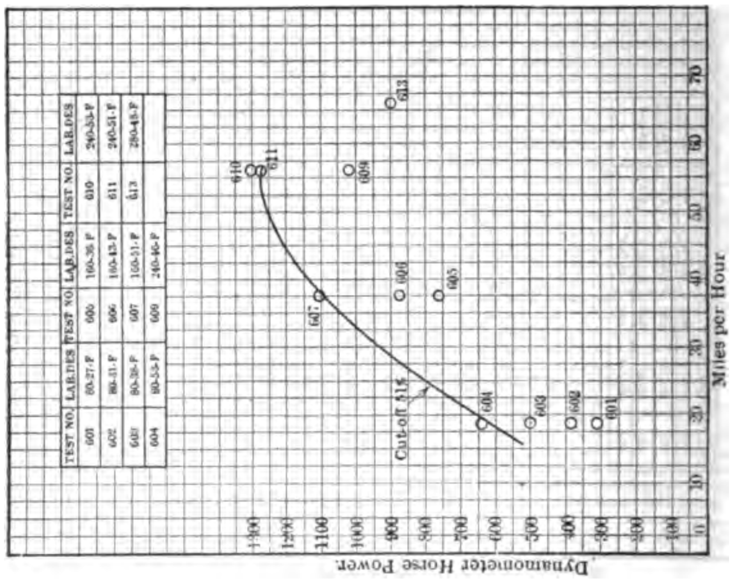
Plot No. 627.



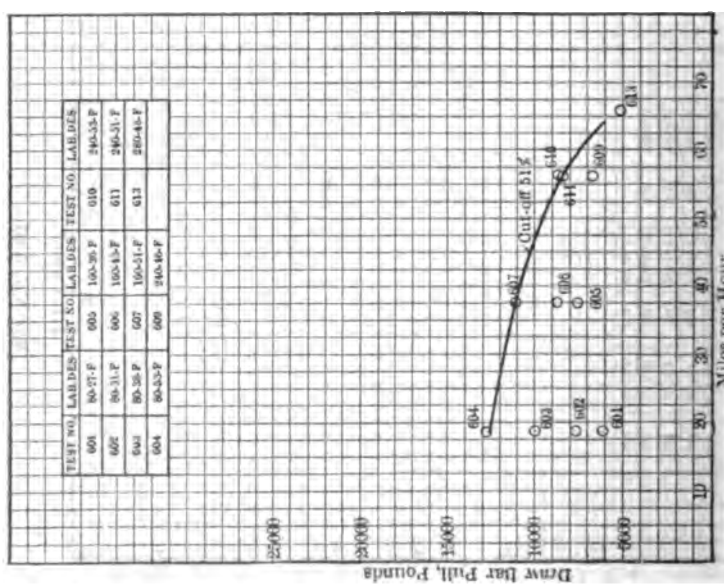
Plot No. 630.



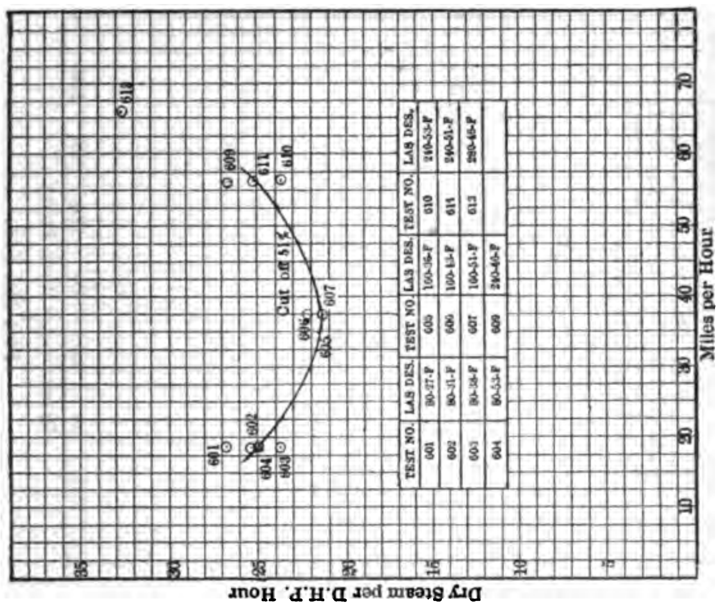
Plot No. 629.



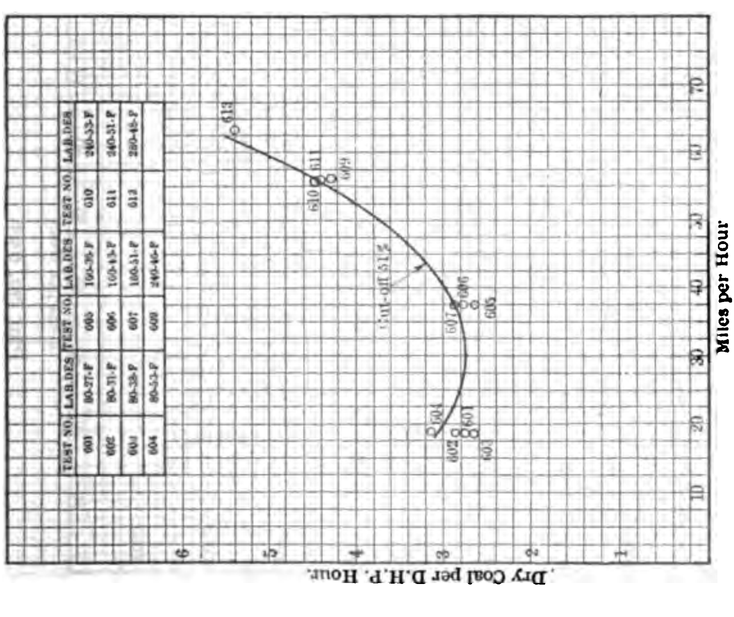
Plot No. 641.



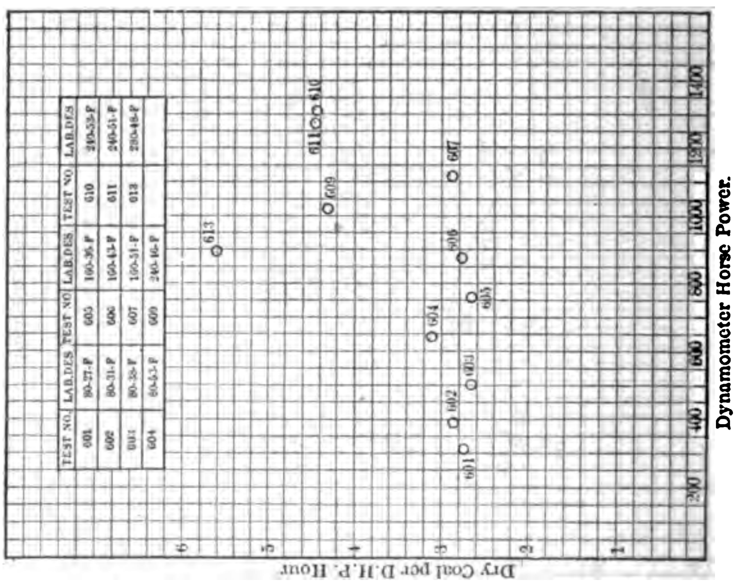
Plot No. 640.



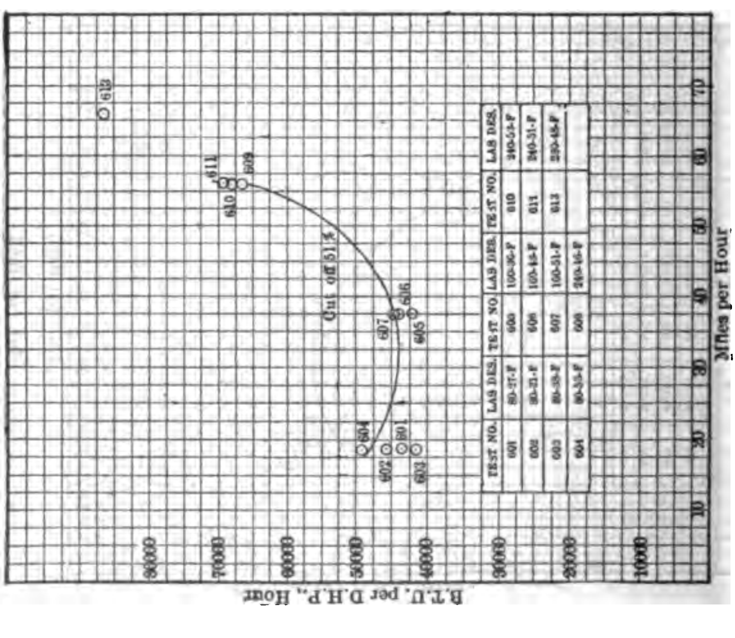
Plot No. 643.



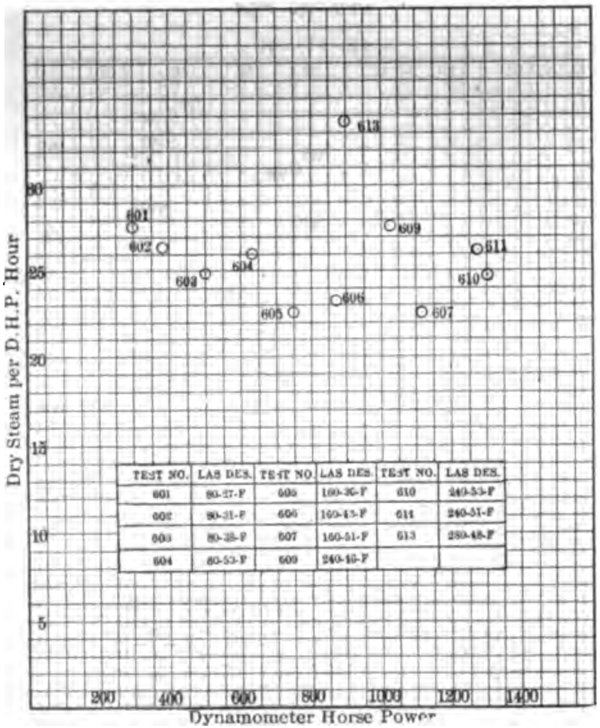
Plot No. 642.



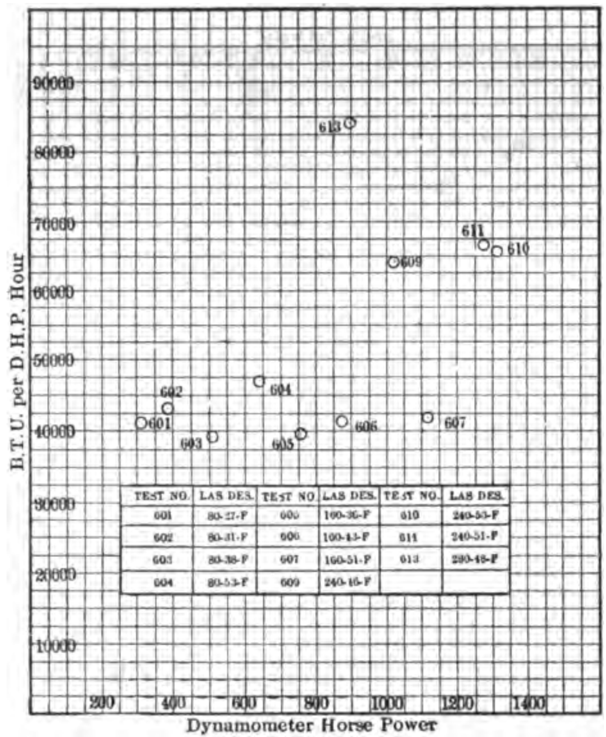
Plot No. 645.



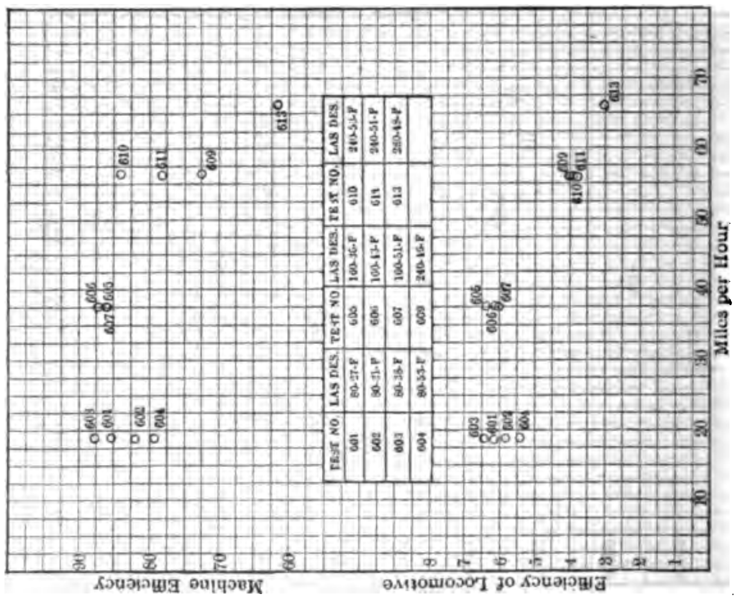
Plot No. 644.



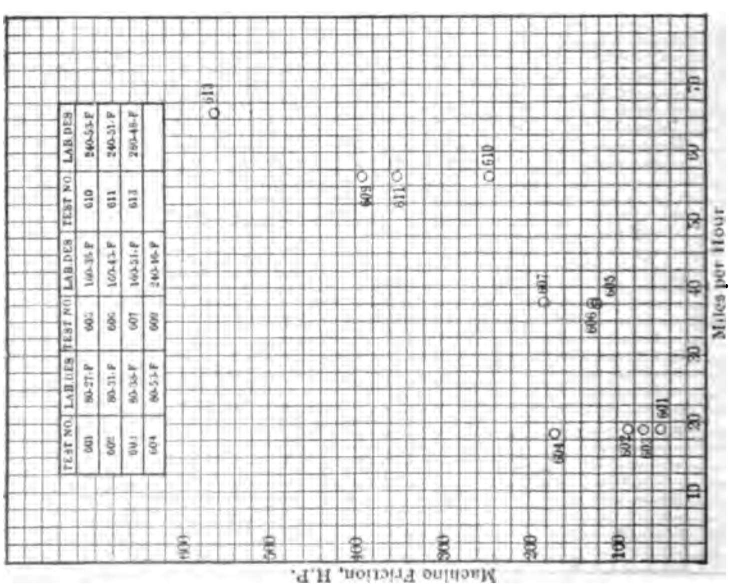
Plot No. 646.



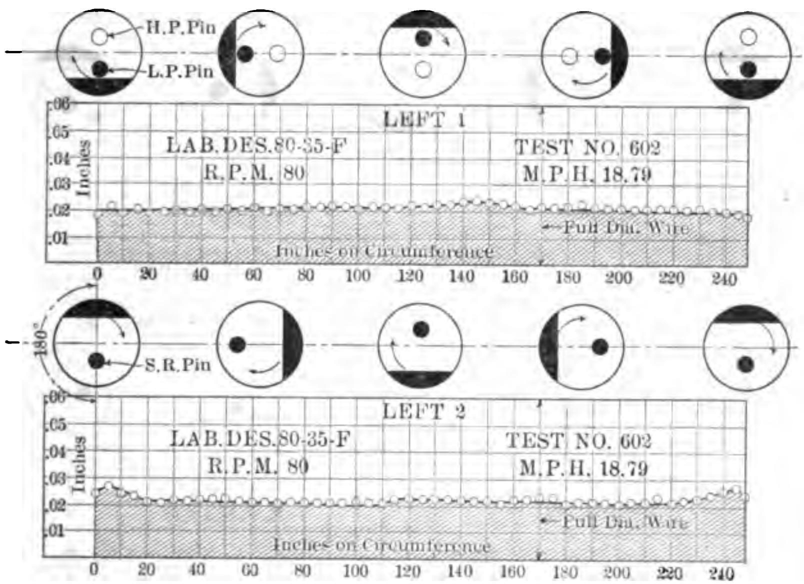
Plot No. 647.



Plot No. 649.

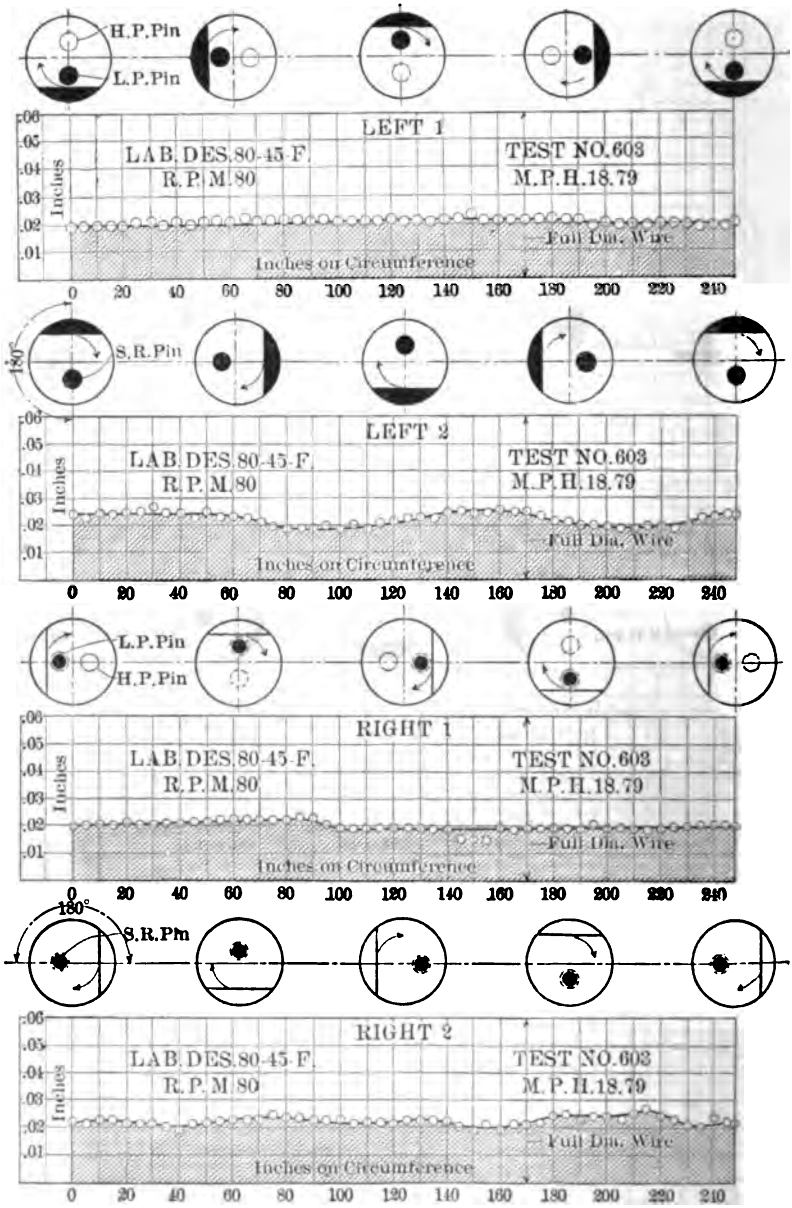


Plot No. 648.

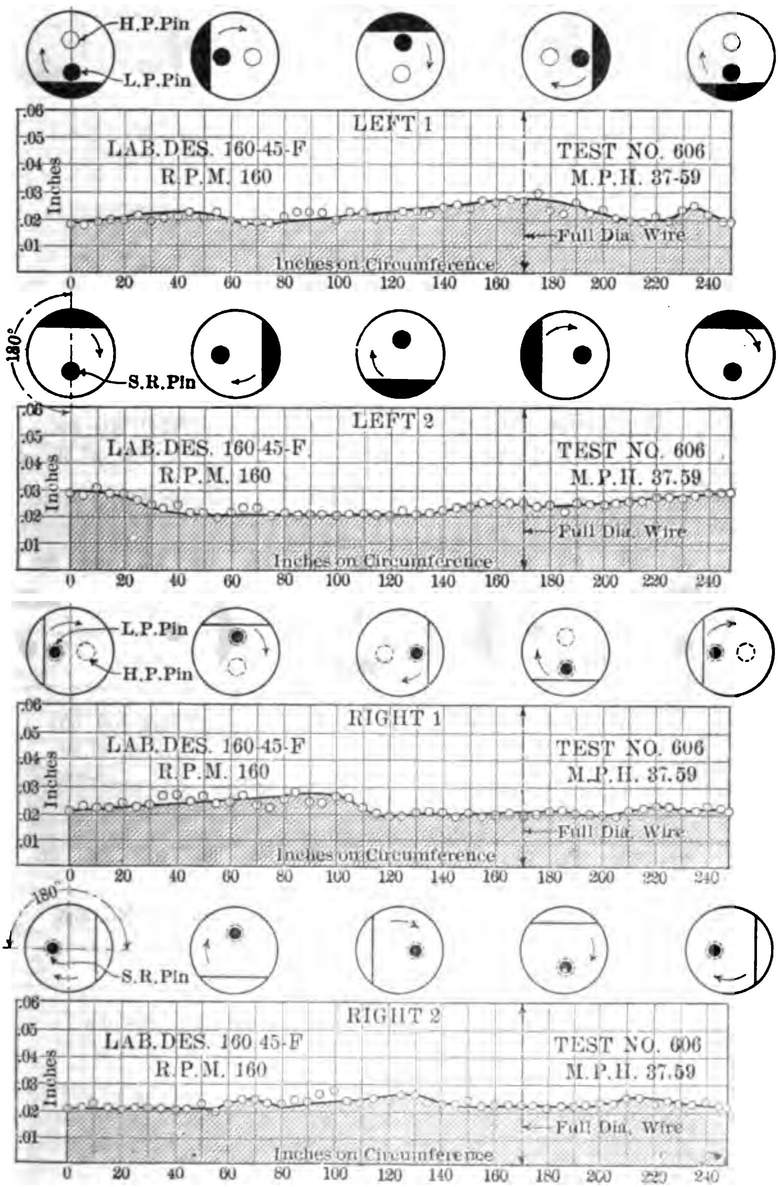


Wire Diagrams for Counterbalance Tests, Locomotive No. 535.

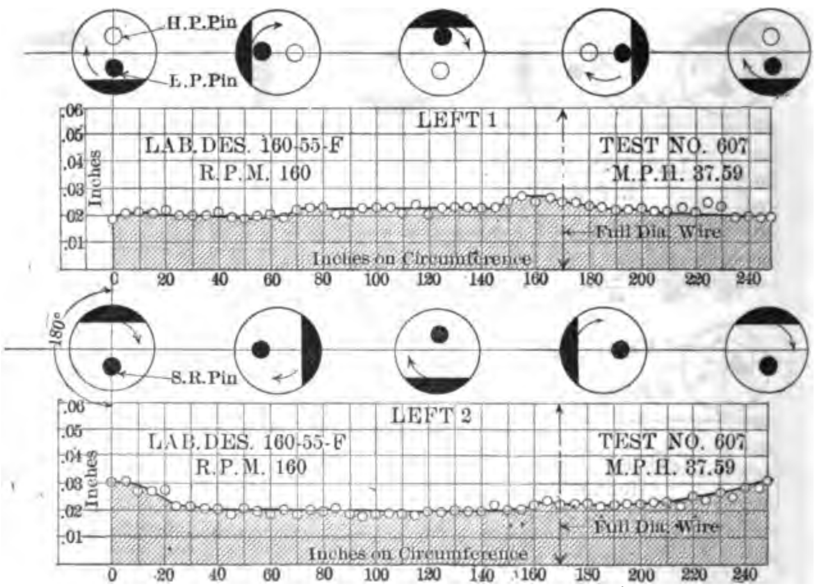
For explanation see page 451.



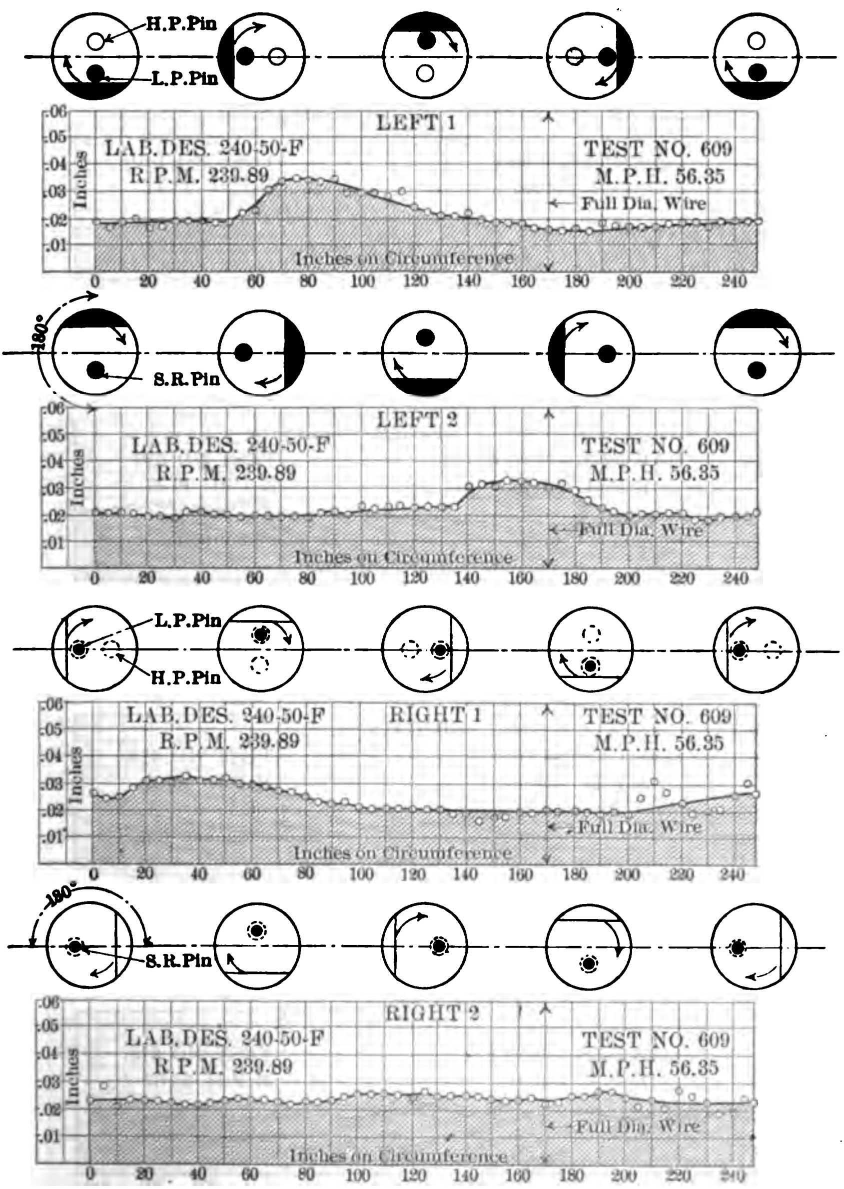
Wire Diagrams for Counterbalance Tests, Locomotive No. 535.



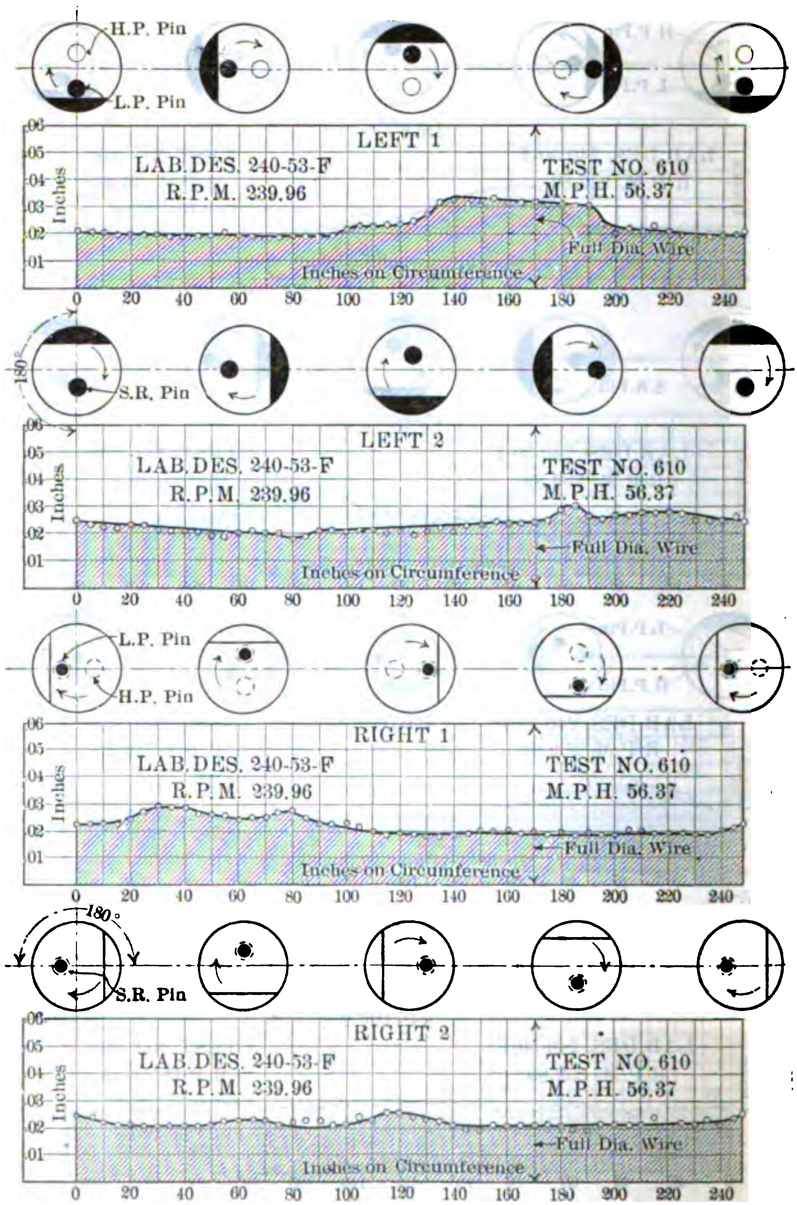
Wire Diagrams for Counterbalance Tests, Locomotive No. 535.



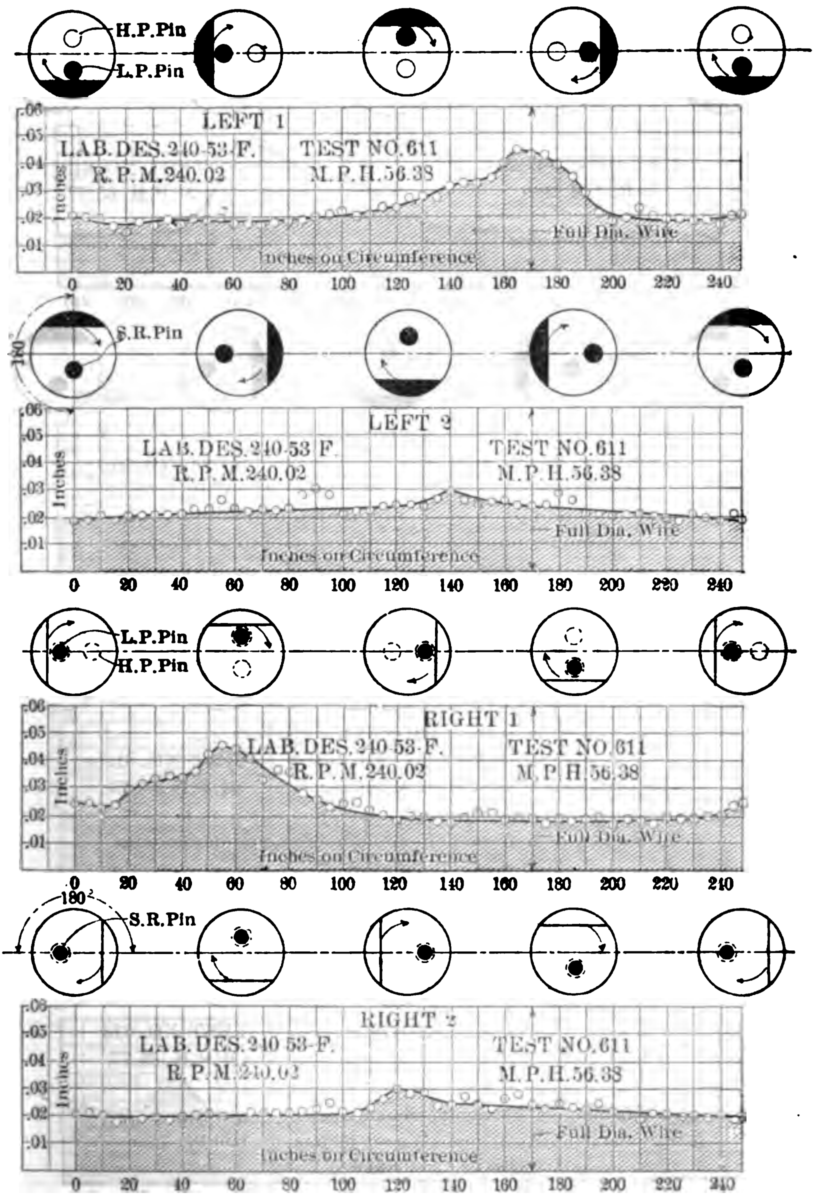
Wire Diagrams for Counterbalance Tests, Locomotive No. 535.



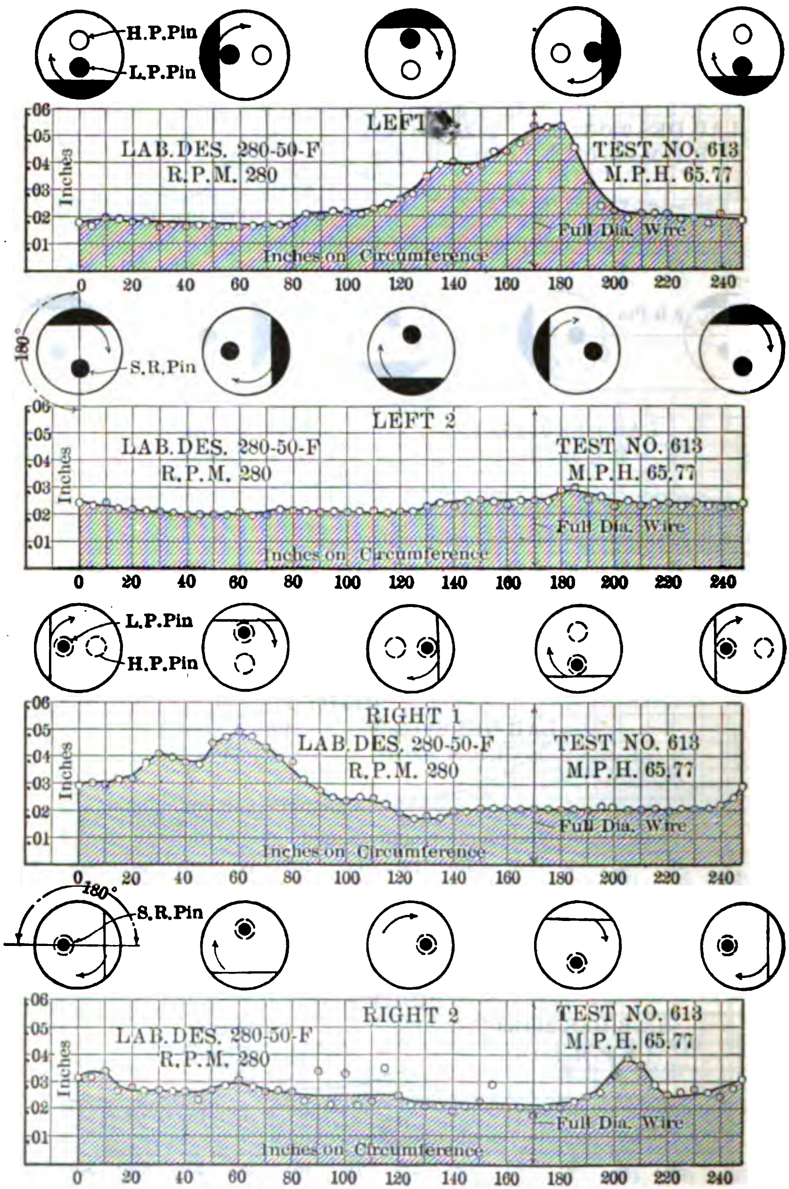
Wire Diagrams for Counterbalance Tests, Locomotive No. 535.



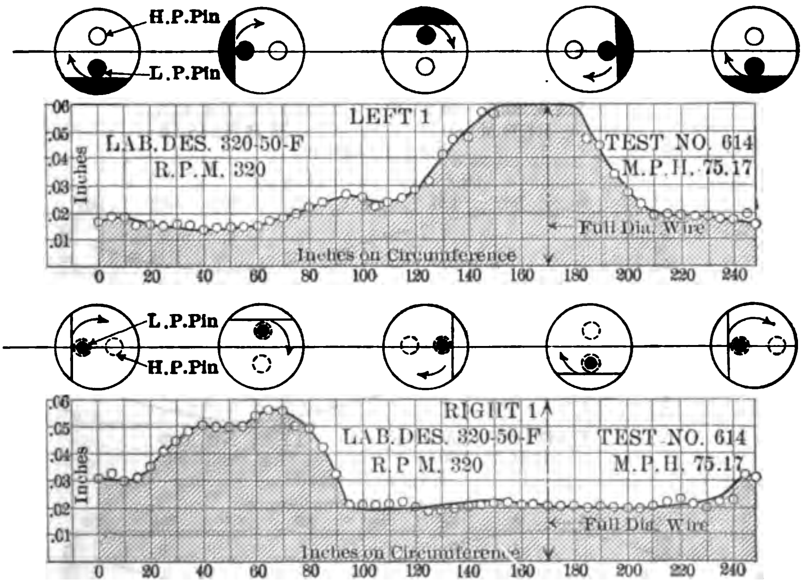
Wire Diagrams for Counterbalance Tests, Locomotive No. 535.



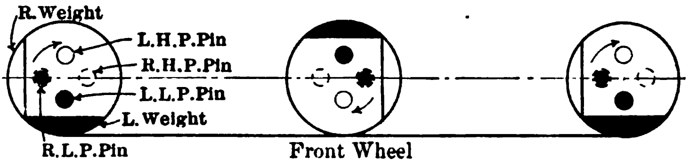
Wire Diagrams for Counterbalance Tests, Locomotive No. 535.

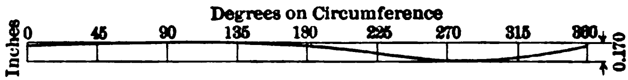


Wire Diagrams for Counterbalance Tests, Locomotive No. 535.

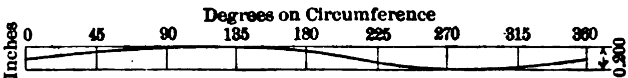


Wire Diagrams for Counterbalance Tests, Locomotive No. 535.

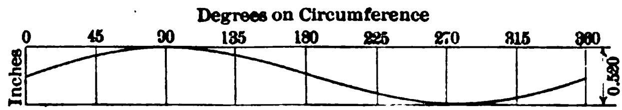




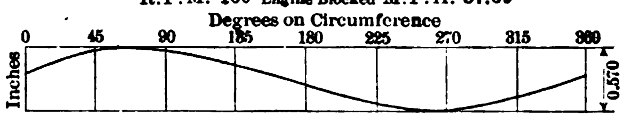
LAB. DES. 80-35-F TEST NO. 602
R.P.M. 80 M.P.H. 18.79



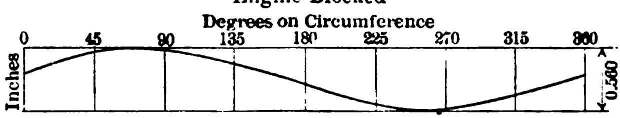
LAB. DES. 80-45-F TEST NO. 603
R.P.M. 80 M.P.H. 18.79
Engine Blocked



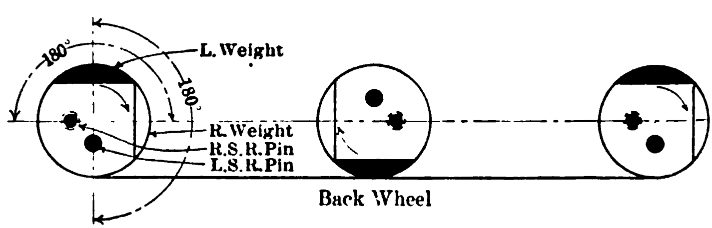
LAB. DES. 160-35-F TEST NO. 605
R.P.M. 160 Engine Blocked M.P.H. 37.59



LAB. DES. 160-45-F TEST NO. 606
R.P.M. 160 M.P.H. 37.59
Engine Blocked

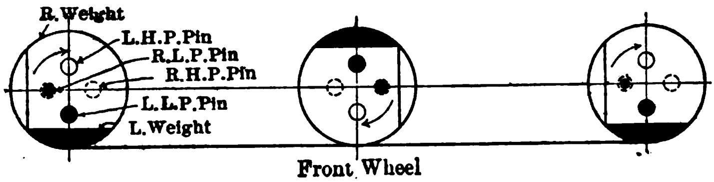


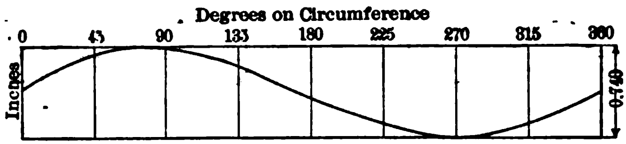
LAB. DES. 160-55-F TEST NO. 607
R.P.M. 160 M.P.H. 37.59
Engine Blocked



Nosing Diagrams, Locomotive No. 585.

Engine Blocked: Wedges were driven between the trailers and rear frames to dampen the vibrations at the rear of the locomotive.

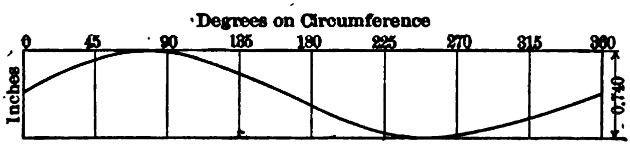




LAB. DES. 240-50-F
R.P.M. 239.89

TEST NO. 609
M.P.H. 56.35

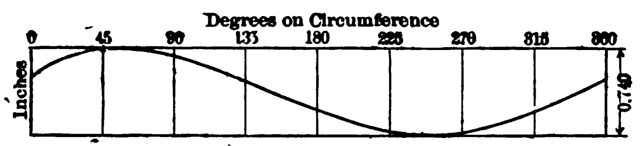
Engine Blocked



LAB. DES. 240-53-F
R.P.M. 239.96

TEST NO. 610
M.P.H. 56.37

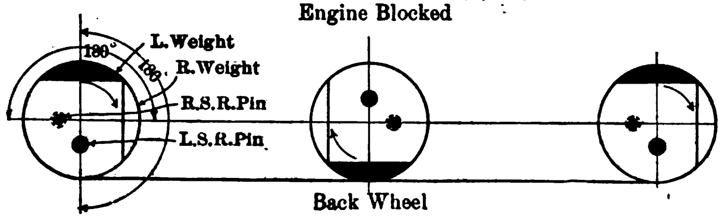
Engine Blocked



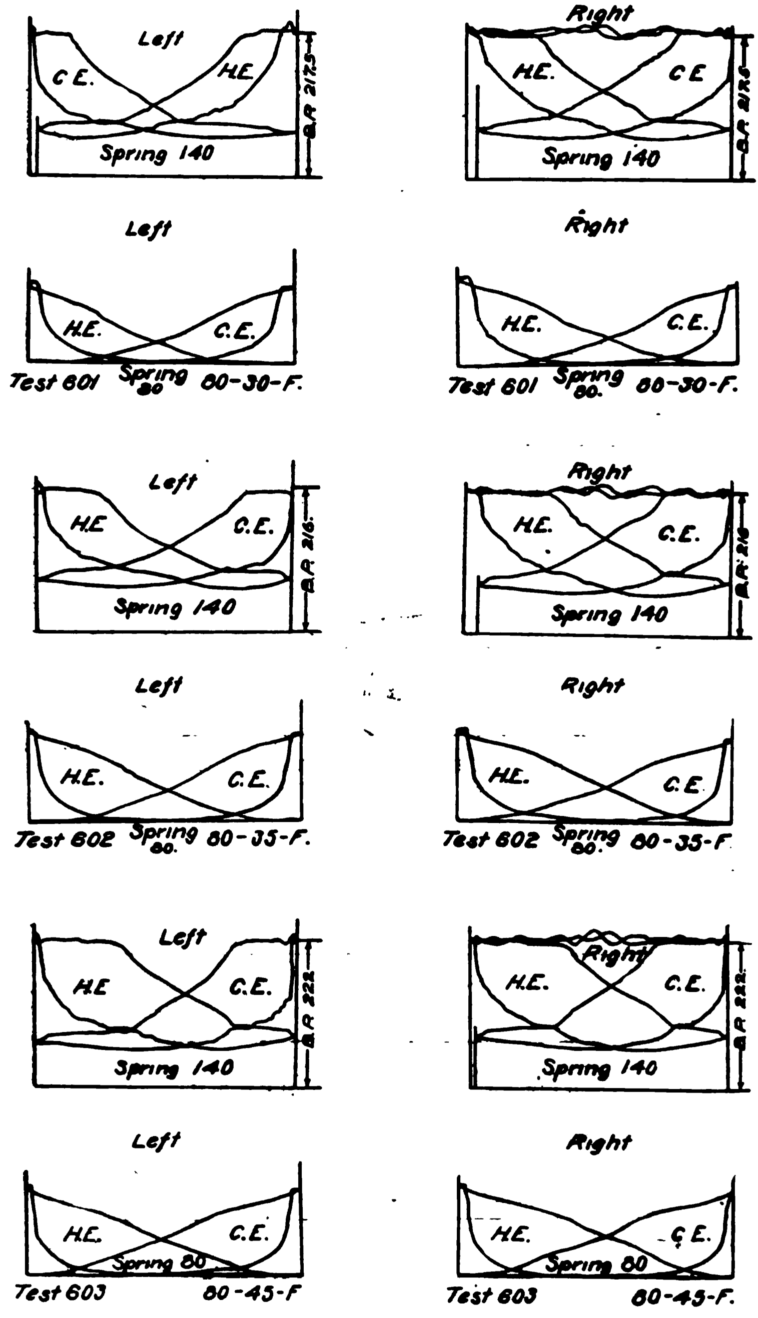
LAB. DES. 280-50-F
R.P.M. 280

TEST NO. 613
M.P.H. 65.77

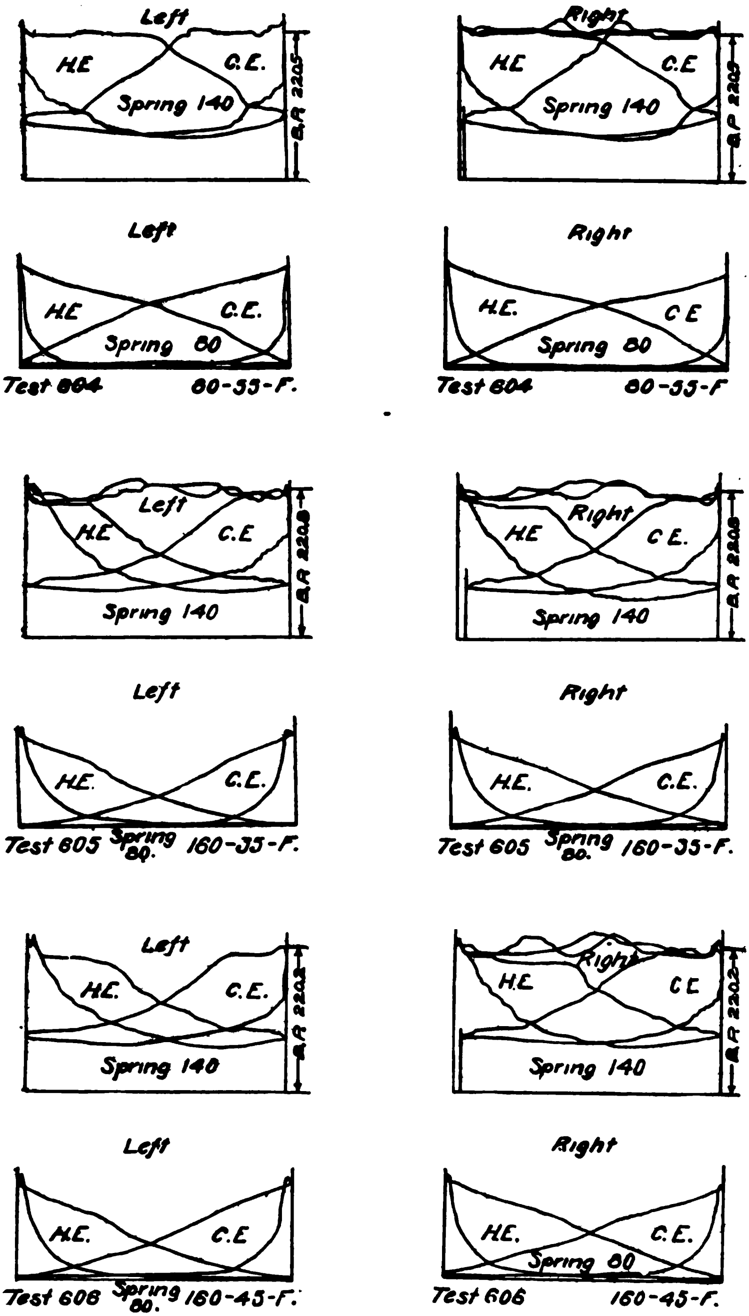
Engine Blocked



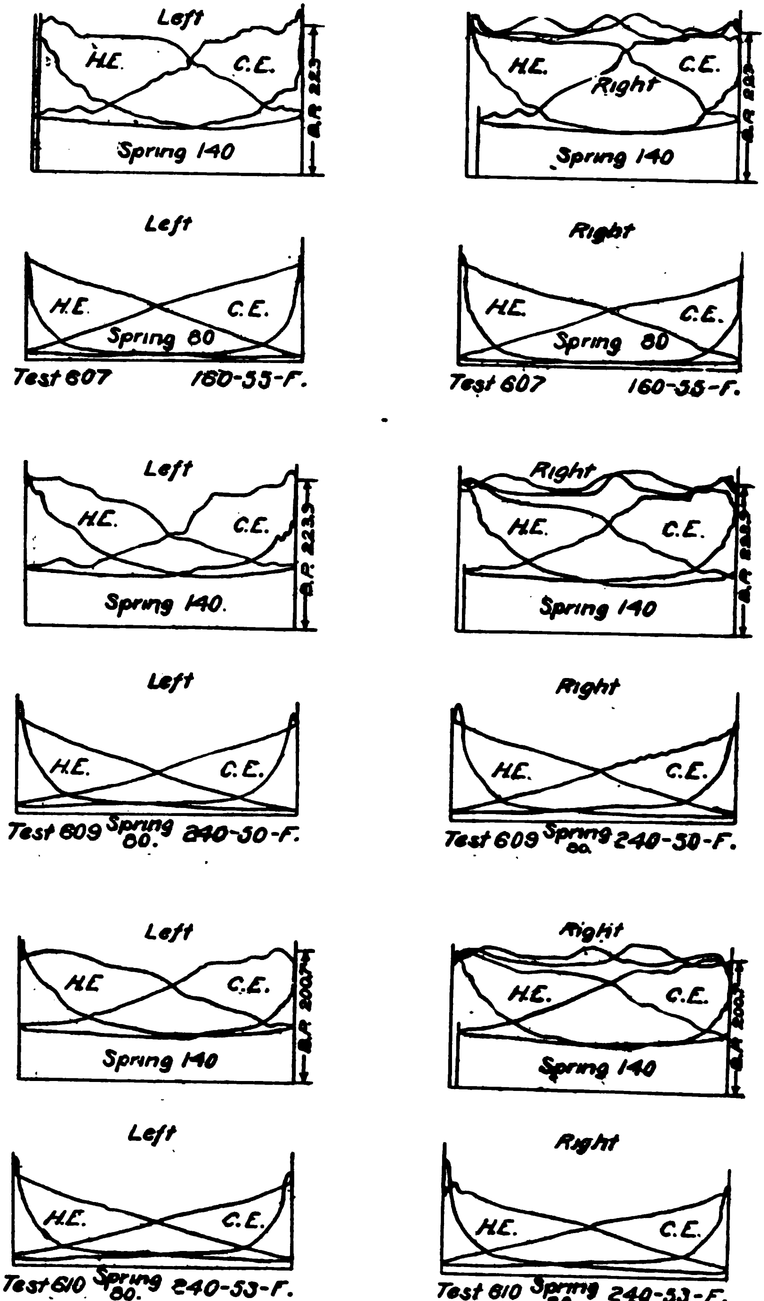
Nosing Diagrams, Locomotive No. 535.



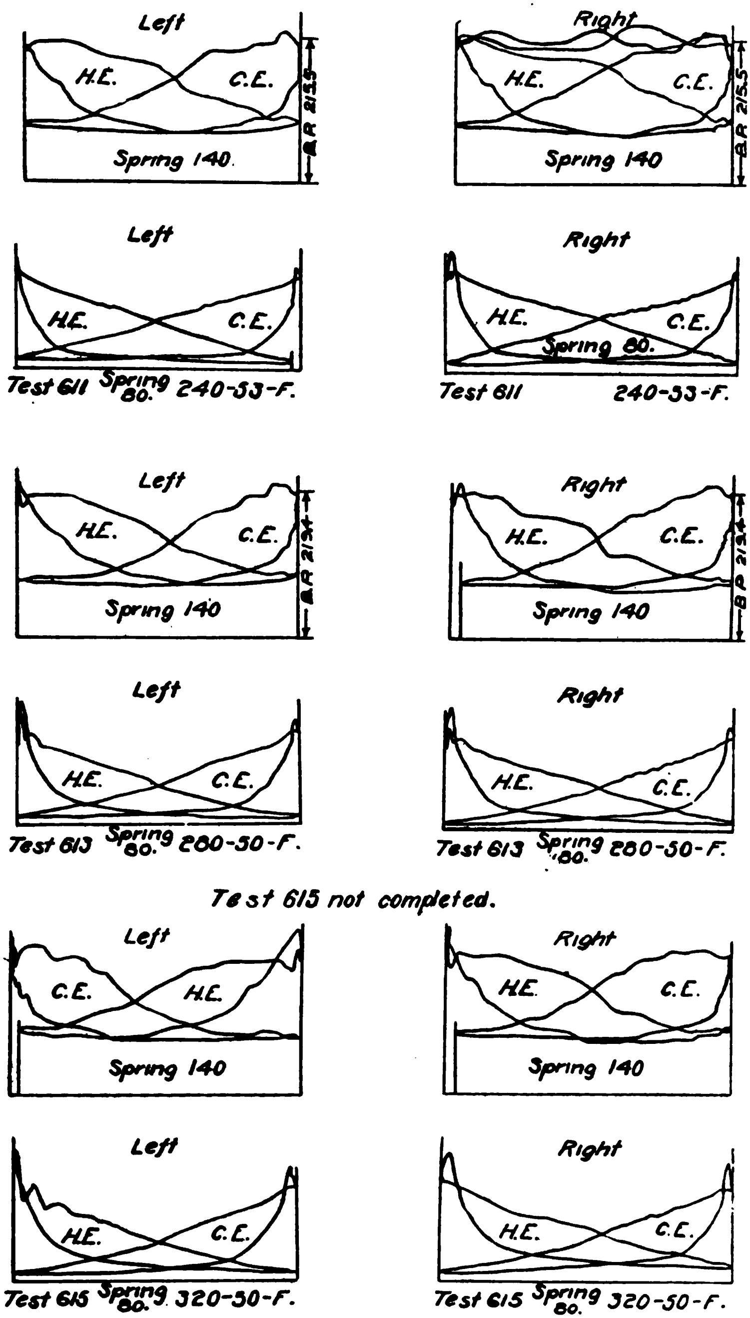
Typical Indicator Diagrams, Locomotive No. 535.



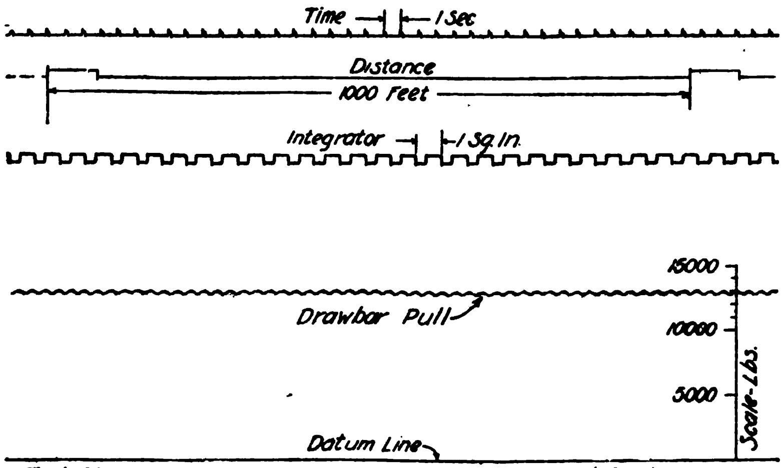
Typical Indicator Diagrams, Locomotive No. 535.



Typical Indicator Diagrams, Locomotive No. 585.



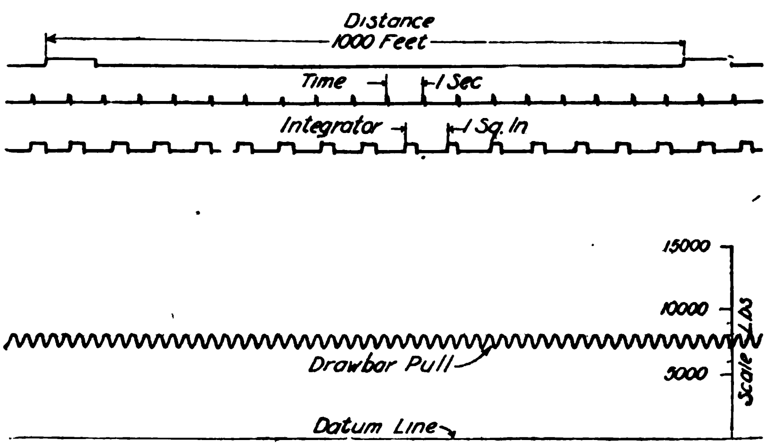
Typical Indicator Diagrams, Locomotive No. 535.



Test 604 Lab Desig 80-55-F

Dashpots in Safety Bars Not Throttled

Speed, 18.79 Miles per Hour.

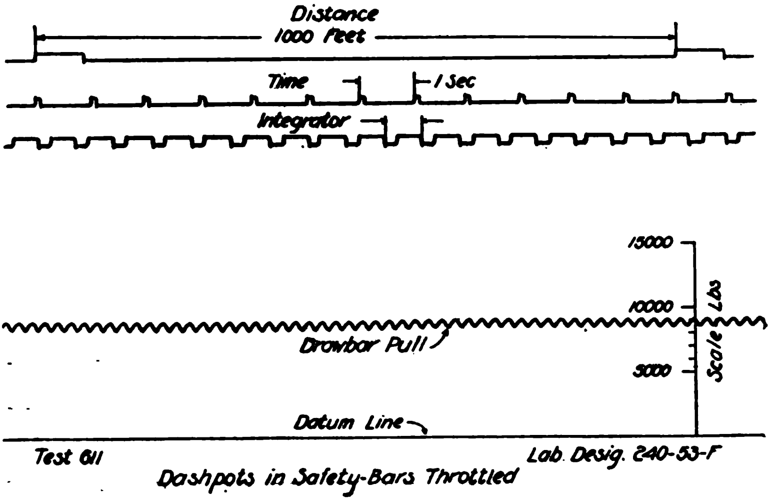


Test 606 Lab. Desig 160-45-F

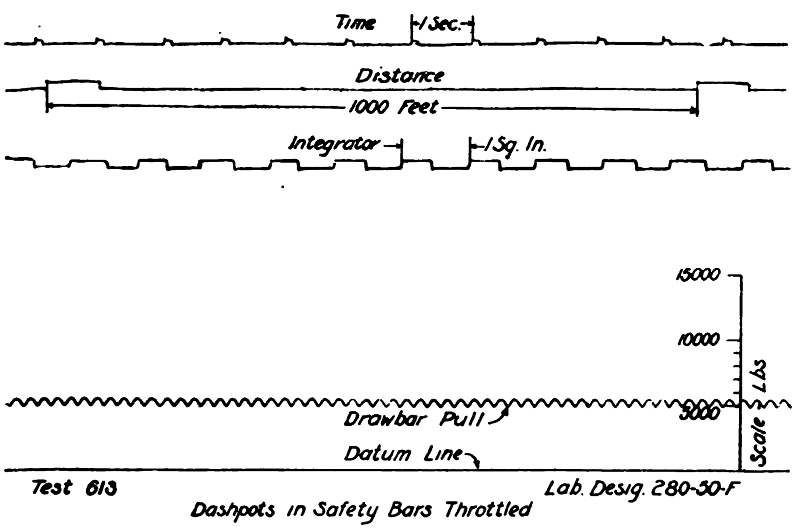
Dashpots in Safety Bars Throttled

Speed, 37.59 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 585.

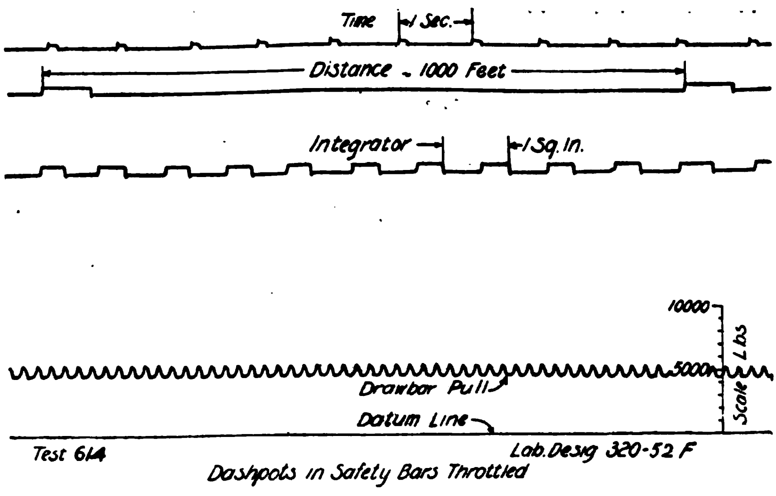


Speed, 56.38 Miles per Hour.



Speed, 65.77 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 535.



Speed, 75.18 Miles per Hour.

Test 614 was not completed.

Typical Dynamometer Diagram, Locomotive No. 585.

Fig. 612.

Elevation, Showing Positions of Instruments,

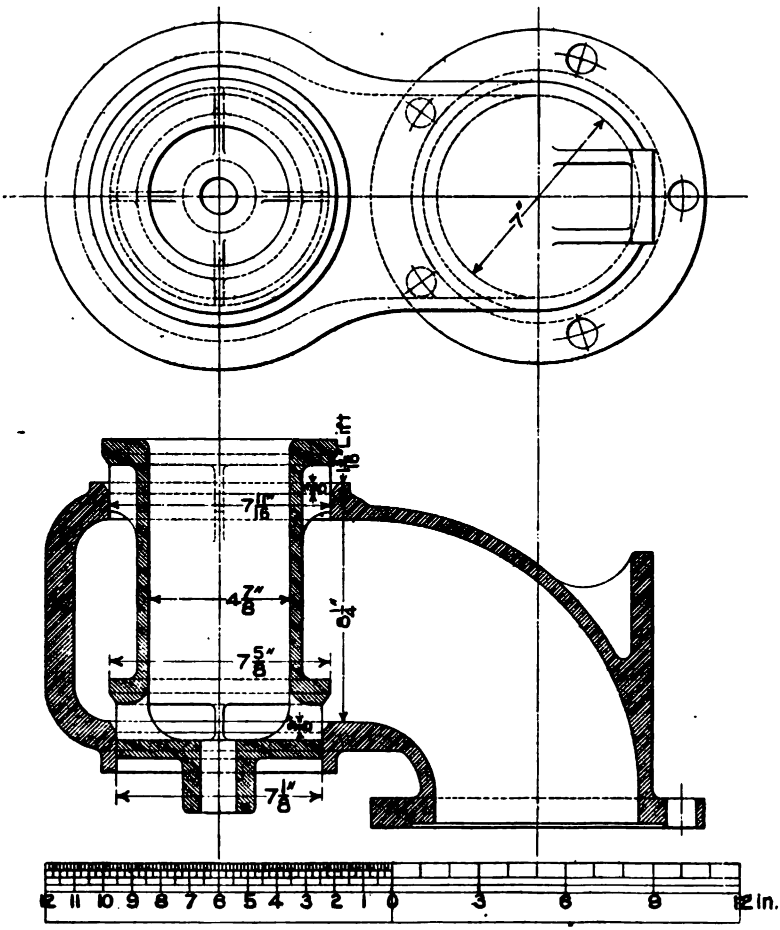


Fig.. 618— Throttle Valve, Locomotive No. 535.

CHAPTER XIX.

TESTS OF ATLANTIC TYPE LOCOMOTIVE, HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

The seventh locomotive tested was No. 628, built by the Hannoversche Maschinenbau - Actien - Gesellschaft, vormals Georg Egestorff, Linden vor Hannover, Germany, and was presented for test by the builders. This locomotive was built for the Hanover directorate of the Royal Prussian Railway Administration (Koeniglich Preuss. Eisenbahn Verwaltung, Direktion Hannover) and was delivered to them at the close of the Exposition.

The locomotive was a four-cylinder balanced compound with superheater, and was known as the S8 class according to the railroad company's classification.

The valve motion was the Heusinger von Waldegg, otherwise known as the Walschaert modified by Von Borries.

The four cylinders were set across the locomotive on the centre line of the leading truck. The two high pressure cylinders were between the frames, and the two low pressure cylinders were outside the frames. The high and low pressure cylinders of each pair were cast in one piece with the corresponding steam chests, and the two groups of cylinders bolted together. The four cylinders were all connected to the forward axle. The cranks of the high pressure and low pressure cylinders, on one side, were set at 180 degrees to each other.

This locomotive was equipped with a Pielock superheater which consisted of a chamber in the shell of the boiler using a portion of the boiler tubes as superheating surface. It was located far enough from the fire-box so that the tubes could not be overheated. The main part of the superheater consisted of a box into which the ends of the boiler tubes were lightly rolled. This box was divided into compartments by plates parallel to the tubes so as to get a long contact of the steam with the heating surface. The steam, at boiler pressure, passed into the superheater and then through the several compartments on its way to the cylinders.

This locomotive was on the testing plant from November 2 until November 12, a period of eleven days. In this time ten tests were made; all of the lost time, except half a day, being due to the locomotive.

The chief difficulty was caused by the inefficiency of the draft appliances. The fire did not burn evenly on the grate, being very intense next to the flue sheet under the brick arch, and very dull and without draft near the fire-door.

There was no diaphragm plate or petticoat pipe in the front end, and the only way to adjust the draft was by changing the size of the nozzle. The height could not be changed, as no other exhaust nozzle pipes were on hand; the nozzle was made smaller, but this, of course, only increased the draft and did not make the fire burn more evenly.

The coal used was unlike that used in Germany. The locomotive was adjusted for burning the German fuel. In addition to the difficulty introduced by the different fuel, the locomotive was, undoubtedly, over-cylindered for American practice. This is clearly shown by the following comparisons of ratios:

LOCOMOTIVE NUMBER	HEATING SURFACE TO CYLINDER VOLUME	GRATE SURFACE TO CYLINDER VOLUME
628 (Hanover)	120.64	2.00
*628 "	101.10	2.00
3000 (N. Y. C.)	139.86	2.32
535 (A. T. & S. F.)	145.83	2.43
2512 (P. R. R.)	154.14	1.93
†E2a (P. R. R.)	236.51	5.69

The critical speed of this locomotive was 200 revolutions and it ran very steadily, showing little tendency to nose or sway.

The tail piece of the locomotive was made of a steel plate three-quarters of an inch thick, and covered the back of the frames, which were of the plate type. It was necessary to attach

* Superheating surface not included.

† This locomotive was not tested but ratios are given above as typical of a simple Atlantic type locomotive.

the fastenings for the dash-pots to this plate, and above 280 revolutions per minute it was not sufficiently stiff to prevent excessive vibration; the action of the dash-pots, therefore, did not protect the dynamometer.

The injectors on this locomotive did not admit of adjusting the feed as closely as American injectors do, so that the injectors had to be put on and off a great many times in the light tests. Consequently, the boiler pressure varied a good deal and considerable water was wasted at the injector over-flow, but as the waste was measured it introduced no error.

The principal dimensions and the details of this locomotive are given in Appendix 700. The principal nominal dimensions are shown in the following table:

Total weight, pounds	133,350
Weight on drivers, pounds	65,350
Cylinders (compound), inches	14 5-32 and 22 x 23 5-8
Diameter of drivers, inches	78
Fire-box heating surface, square feet	105.59
Heating surface in tubes (water side), not including superheater, square feet	1511.94
Heating surface of superheater (fireside), square feet	283.79
Total heating surface (based on water side of tubes), including superheater, square feet	1932.16
*Total heating surface (based on fire side of tubes), including superheater, square feet	1753.15
Grate area, square feet	29.06
Boiler pressure, pounds per square inch	200
Valves	High pressure, piston; low pressure, Allen balanced
Valve motion	Von Borries simplified Heusinger von Waldegg
Fire-box, type	Wide
Number of tubes in boiler	241
" " " " superheater	241
Outside diameter of tubes, inches	2
Length of tubes (not including superheater), inches	143.78
" " " in superheater, inches	29.92

The maximum tractive effort was 19,459 pounds working simple and 13,789 pounds working compound. The ratio of weight on drivers to maximum tractive effort when working simple was 3.36:1 and 4.74:1 working compound.

* Used in Calculations.

TESTS.

The tests which were run, together with the laboratory designation and dates of running are given below:

TEST NO.	LABORATORY DESIGNATION.	DATE.
701	80-35-F	November 4th.
702	80-45-F	" 4th.
705	160-35-F	" 5th.
706	160-40-F	" 8th.
707	160-45-F	" 7th.
708	160-45-F	" 12th.
709	240-30-F	" 10th.
710	240-35-F	" 9th.
711	240-40-F	" 11th.
712	280-30-F	" 12th.

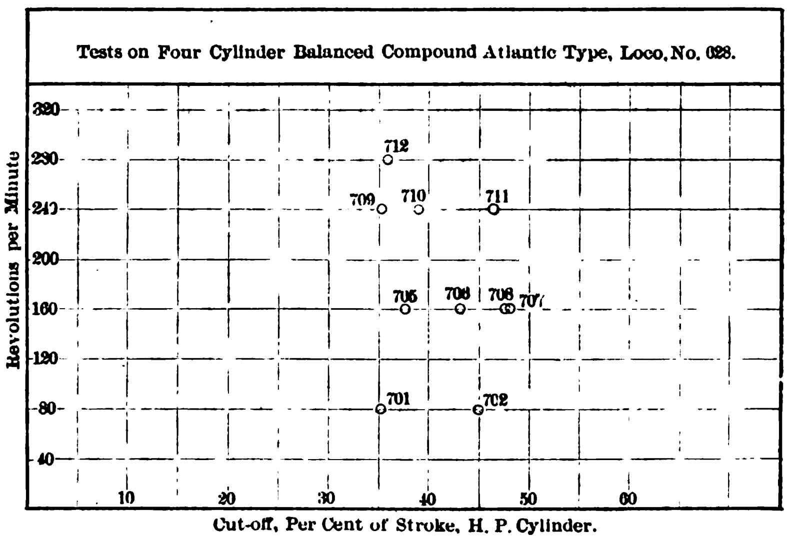


Fig. 701.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 701.

The lowest average boiler pressure was 187.0 pounds, while the highest was 204.2 pounds. The temperature of the feed water was very uniform, the range of temperature being 6.8 degrees.

The total coal fired per square foot of grate area follows:
In 2 tests.............................. less than 100 pounds
In 3 tests...................... between 100 and 150 pounds.
In 3 tests...................... between 150 and 200 pounds
In 2 tests...................... between 200 and 250 pounds

EVAPORATION—TABLE 702.

The evaporation per hour was between the limits of 7,378 pounds and 15,804 pounds.

TABLE No. 701—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
701	80-35 F	180	198.8	14.443	59.2	55.6	108.95
702	80-45-F	180	202.0	14.425	64.7	58.8	125.70
709	240-30-F	120	204.1	14.540	44.9	54.5	110.96
705	160-35-F	180	198.8	14.462	55.7	55.7	158.45
710	240-35-F	60	191.1	14.393	48.0	53.8	75.40
706	160-40-F	180	202.6	14.481	51.8	56.1	191.40
708	160-45-F	129.96	197.0	14.534	37.5	52.1	200.00
707	160-45-F	139.98	198.8	14.443	55.2	53.8	217.13
712	280-30-F	30	204.2	14.455	45.9	52.0	44.02
711	240-40-F	79.98	187.0	14.651	45.8	53.6	163.28

The quality of steam in the steam dome (before entering superheater) was obtained by means of a throttling calorimeter, and it is of interest to note that it was exceptionally high, the moisture never exceeding .51 of one per cent.

The temperature of the superheated steam after leaving the superheater and just before entering the dry pipe was obtained by a special mercurial thermometer.

The lowest superheat was 160.9 degrees Fahrenheit and the highest 192.0 degrees.

The amount of superheating does not appear to be materially affected by different rates of combustion or evaporation.

A throttling calorimeter was on the branch pipe, to ascertain the amount of superheating just before entering the cylinders, but the formula for calculating the quality of the steam involves the specific heat, and as there is considerable difference of opinion regarding the specific heat of superheated steam, and no law has yet been discovered which governs its variations, these results cannot be said to be exact data. In the formula for obtaining the degrees of superheat (see page 90) the specific heat appears in the denominator, and as the figure used (.48) is certainly too

TABLE No. 702—EVAPORATION.

Identification of Test			Water and Steam		Calorimeter Results			
Test Number	Laboratory Designation	Duration of Test, Minutes	Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Degrees of Superheat of steam in Superheater	Degrees Superheat in Branch Pipe	Equivalent Evaporation Lbs. Per Hour
		Cal.	204	840	*228	218	230	344
701	80–35–F	180	22134	7378	.9984	160.9	84.45	9560
702	80–45–F	180	27529	9176	.9968	192.0	86.97	12000
709	240–30–F	120	22274	11137	.9969	179.8	88.86	14620
705	160–35–F	180	33845	11282	.9949	181.6	82.18	14720
710	240–35–F	60	12710	12710	.9979	179.4	83.87	16670
706	160–40–F	180	38365	12788	.9978	180.9	108.98	16696
708	160–45–F	129.96	32523	15014	.9956	186.2	97.19	19725
707	160–45–F	139.98	35446	15193	.9986	167.1	116.20	19789
712	280–30–F	30	7622	15244	.9936	171.5	71.28	19918
711	240–40–F	79.98	21068	15804	.9977	190.7	101.46	20834

small rather than too large, a larger specific heat would give a smaller number of degrees of superheat.

As the superheated steam passed through a dry pipe surrounded by saturated steam at a temperature of from 150 to 190 degrees lower, it is evident that it would lose a considerable proportion of its superheat.

BOILER POWER—TABLE 703.

The equivalent pounds of water evaporated per square foot of grate surface per hour ranged from 329.0 to 716.9.

The equivalent evaporation per square foot of heating surface ranged from 5.45 to 11.88 pounds per hour.

The maximum boiler horse power developed was 603.9, the horse power being calculated on the usual basis.

The horse power developed per square foot of heating surface ranged from .158 to .345.

The maximum horse power developed per square foot of grate surface was equivalent to about one horse power for each .048 square foot of grate surface. In all of these figures concerning the equivalent evaporation and boiler power the heat absorbed by the superheater has been credited to the boiler.

TABLE No. 703—BOILER POWER.

Identification of Test			Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation	Duration of Test, Minutes	Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft of Grate Surface
		Cal.	Cal.	345	349	Cal.	Cal.
701	80-35-F	180	329.0	5.45	277.1	.158	9.54
702	80-45-F	180	413.0	6.85	347.9	.198	11.97
709	240-30-F	120	503.1	8.34	423.8	.242	14.58
705	160-35-F	180	506.6	8.40	426.7	.243	14.68
710	240-35-F	60	573.7	9.51	483.2	.276	16.63
706	160-40-F	180	574.5	9.52	484.0	.276	16.66
708	160-45-F	129.96	678.8	11.25	571.8	.326	19.68
707	160-45-F	139.98	681.0	11.29	573.6	.327	19.74
712	280-30-F	30	685.2	11.36	577.2	.329	19.86
711	240-40-F	79.98	716.9	11.88	603.9	.345	20.78

COAL AND RATE OF COMBUSTION—TABLE 704.

The total dry coal fired ranged from 1,262 pounds to 6,249 pounds, and the amount per hour from 997 pounds to 3,523 pounds.

The dry coal fired per square foot of grate area per hour ranged from 34.31 pounds to 121.3 pounds.

The increase in the rate of combustion was not regular.

The coal fired per square foot of heating surface per hour ranged from .569 to 2.010 pounds.

CINDERS AND SPARKS—TABLE 705.

The maximum calorific value of the cinders was 13,652 B. T. U., and the maximum calorific value of the sparks was 13,225 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 706.

Relations derived from Figs. 702 to 704 inclusive are given

TABLE No. 704—COAL AND RATE OF COMBUSTION.

Identification of Test				Fuel in Pounds				Rate of Combustion	
Test Number	Laboratory Designation	Duration of Test, Minutes	Total Dry Coal Fired	Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq. Ft. of Grate Per Hour	Dry Coal Per Sq. Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
701	80–35–F	180	2991	2860	997	953	34.31	.569
702	80–45–F	180	3618	3408	1206	1136	41.51	.688
709	240–30–F	120	3185	2948	1592	1474	54.80	.908
705	160–35–F	180	4562	4324	1521	1441	52.33	.868
710	240–35–F	60	2165	2025	2165	2025	74.51	1.235
706	160–40–F	180	5497	5182	1832	1727	63.06	1.045
708	160–45–F	129.96	5747	5393	2653	2490	91.29	1.518
707	160–45–F	139.98	6249	5864	2679	2513	92.18	1.528
712	280–30–F	30	1262	1186	2525	2372	86.88	1.440
711	240–40–F	79.98	4698	4234	3523	3176	121.30	2.010

TABLE No. 705—CINDERS AND SPARKS.

Identification of Test			Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation	Duration of Test, Minutes	Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
701	80–35–F	180	69.7	83.7	153.3	13225	12799
702	80–45–F	180	55.0	10.7	65.7	12585	12165
709	240–30–F	120	112.0	19.5	131.5	13225	12799
705	160–35–F	180	95.3	10.0	105.3	13225	12372
710	240–35–F	60	340.0	58.0	398.0	13438	13225
706	160–40–F	180	144.7	12.3	157.0	13438	11945
708	160–45–F	129.96	424.7	42.0	466.7	13225	12799
707	160–45–F	139.98	436.3	53.6	489.9	12799	11732
712	280–30–F	30	——	——	——	——	——
711	240–40–F	79.98	606.8	112.5	719.3	13652	13225

below. The methods employed in obtaining these equations are explained in detail in Chapter XIII.

$$D = .034\ G \qquad (701)$$

$$T_f = .708\ G + 2055 \qquad (702)$$

$$T_s = 2.04\ G + 515 \qquad (703)$$

$$T_f - T_s = 1540 - 1.33\ G \qquad (704)$$

$$H = .077\ G + 4 \qquad (705)$$

$$G = 1157.8 - .752\ (T_f - T_s) \qquad (706)$$

$$G = 12.99\ H - 52 \qquad (7C7)$$

$$H = 93.36 - .058\ (T_f - T_s) \qquad (708)$$

TABLE No. 706—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water			Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In Smoke-Box	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	224	225	212	207	339
701	80–35–F	180	.88	.56	.19	2049	561	34.31
702	80–45–F	180	1.29	.68	.17	2108	597	41.51
709	240–30–F	120	1.70	1.02	.12	1950	651	54.80
705	160–35–F	180	1.69	.81	.19	2110	629	52.33
710	240–35–F	60	2.17	1.55	.21	2118	639	74.51
706	160–40–F	180	2.22	1.09	.21	2118	670	63.06
708	160–45–F	129.96	3.57	1.82	.38	2062	709	91.29
707	160–45–F	139.98	2.94	1.22	.24	2253	707	92.18
712	280–30–F	30	3.50	1.17	.29	2043	676	86.88
711	240–40–F	79.98	3.70	1.86	.22	2048	787	121.30

The fire-box temperatures were very uniform, and ranged from 1,950 to 2,253 degrees Fahrenheit. The smoke-box temperatures ranged from 561 to 787 degrees.

EVAPORATIVE PERFORMANCE—TABLE 707.

The equivalent evaporation per pound of dry coal ranged from 9.95 pounds to 5.91 pounds.

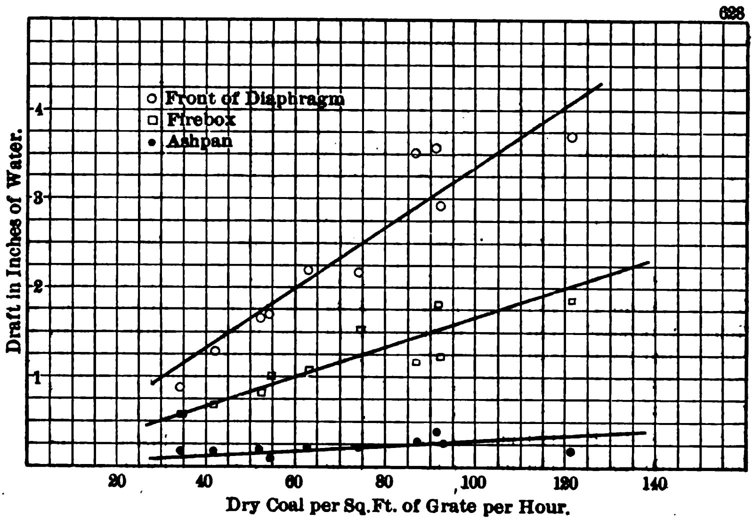


Fig. 702.— Draft and Rate of Combustion.

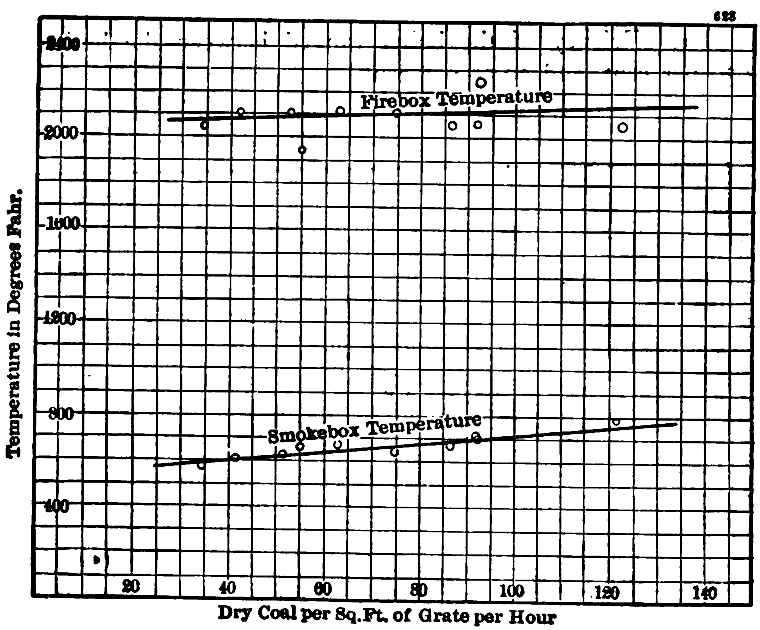


Fig. 703.— Fire-box and Smoke-box Tpmperatures.

TABLE No. 707—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
701	80–35–F	180	7.33	9.57	10.00	15082	61.22
702	80–45–F	180	7.54	9.95	10.57	15182	63.30
709	240–30–F	120	6.91	9.18	9.92	14905	59.49
705	160–35–F	180	7.35	9.68	10.21	15071	62.08
710	240–35–F	60	5.80	7.70	8.28	15108	49.22
706	160–40–F	180	6.90	9.11	9.67	15108	58.28
708	160–45–F	129.96	5.60	7.49	7.92	14904	48.22
707	160–45–F	189.98	5.62	7.39	7.87	15076	47.33
712	280–30–F	80	5.96	7.89	8.39	15018	50.73
711	240–40–F	79.98	4.44	5.91	6.56	14436	39.55

The heating value of the coal was practically uniform for all the tests.

The efficiency of the boiler ranged between the limits of 63.30 per cent. and 39.55 per cent.

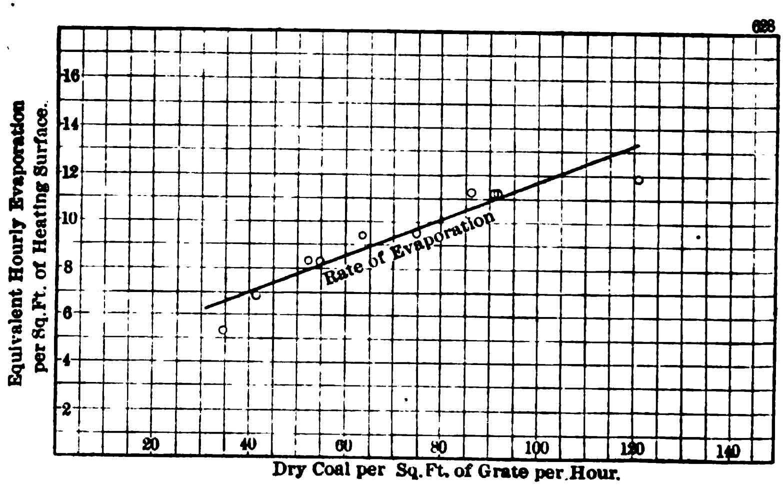


Fig. 704.— Rates of Combustion and Evaporation.

From Fig. 705 the relation between H and E was found to be:

$$E = 13.19 - .51\ H \quad \ldots\ldots\ldots\ldots\ldots (709)$$

SMOKE-BOX GASES—TABLE 708.

The percentage of oxygen ranged from 9.93 per cent. to 4.3 per cent.

The percentage of CO increased as the rate of evaporation

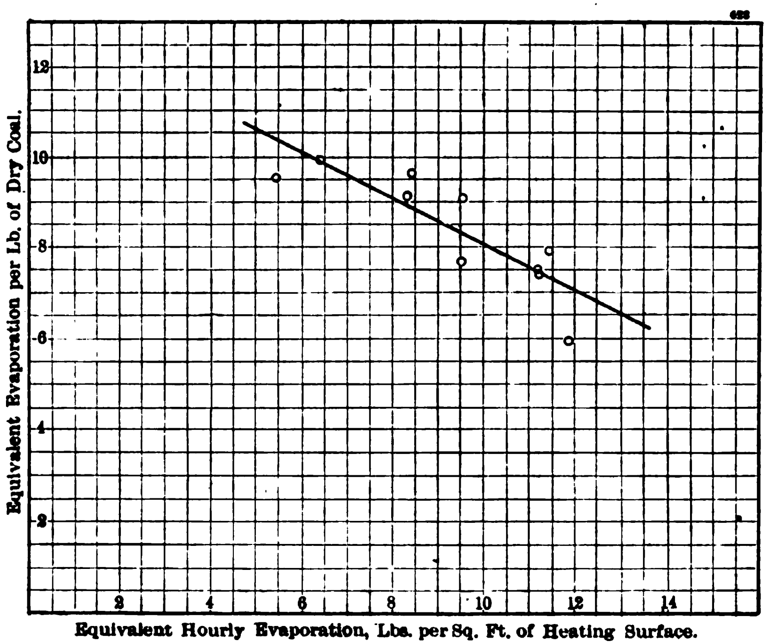


Fig. 705.— Rate of Evaporation and Evaporation per Lb. of Coal.

increased—the range for this locomotive being between the limits of .17 per cent and 4.0 per cent.

The carbon dioxide, CO_2, ranged from 7.97 per cent. to 11.77 per cent.

The heat lost by imperfect combustion ranged from 1.08 per cent. to 16.12 per cent.

PERFORMANCE OF ENGINES.

The results in tables 709 and 710 are arranged with reference to the speed of the locomotive, the tests at each speed being

TABLE No. 708—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
701	80–35–F	180	9.93	.17	8.83	81.07	14934	1.08
702	80–45–F	180	9.33	1.20	8.47	81.00	15040	7.05
709	240–30–F	120	6.30	.57	11.77	81.36	14721	2.68
705	160–35–F	180	6.43	.60	11.47	81.50	14931	2.84
710	240–35–F	60	6.15	2.30	10.05	81.50	14933	10.65
706	160–40–F	180	8.40	.47	10.20	80.93	14933	2.52
708	160–45–F	129.96	4.43	3.30	10.93	81.34	14827	13.36
707	160–45–F	139.98	4.73	1.57	11.33	82.37	14934	6.96
712	280–30–F	30	4.30	4.00	10.30	81.40	14827	16.12
711	240–40–F	79.98	8.93	1.73	7.97	81.37	14293	10.66

TABLE No. 709—GENERAL ENGINE CONDITIONS.

Identification of Test		Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke H. P. Cylinder	Steam Pressure	
Test Number	Laboratory Designation					In Boiler Lbs. Per Sq. In.	In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	217	220
701	80–35–F	180	80.00	18.57	35.2	198.3	194.6
702	80–45–F	180	80.00	18.57	44.9	202.0	198.3
705	160–35–F	180	160.00	37.13	37.6	196.8	194.4
706	160–40–F	180	160.06	37.15	43.2	202.6	197.4
707	160–45–F	139.98	160.00	37.13	47.8	198.8	193.6
708	160–45–F	129.96	160.00	37.13	47.4	197.0	190.9
709	240–30–F	120	240.00	55.70	35.3	204.1	198.5
710	240–35–F	60	239.43	55.57	38.8	191.1	185.1
711	240–40–F	79.98	240.00	55.70	46.4	187.0	179.9
712	280–30–F	30	280.27	65.05	35.8	204.2	196.6

grouped. The tests in each group are arranged with reference to the nominal cut-off in the high pressure cylinders.

While the cut-offs in the high and low pressure cylinders were controlled by a single reversing gear and had a fixed relation to each other, the cut-off in the low pressure cylinder was about 17 per cent. later than that in the high pressure cylinder.

GENERAL ENGINE CONDITIONS—TABLE 709.

The lowest speed at which any test was run was 18.57 miles

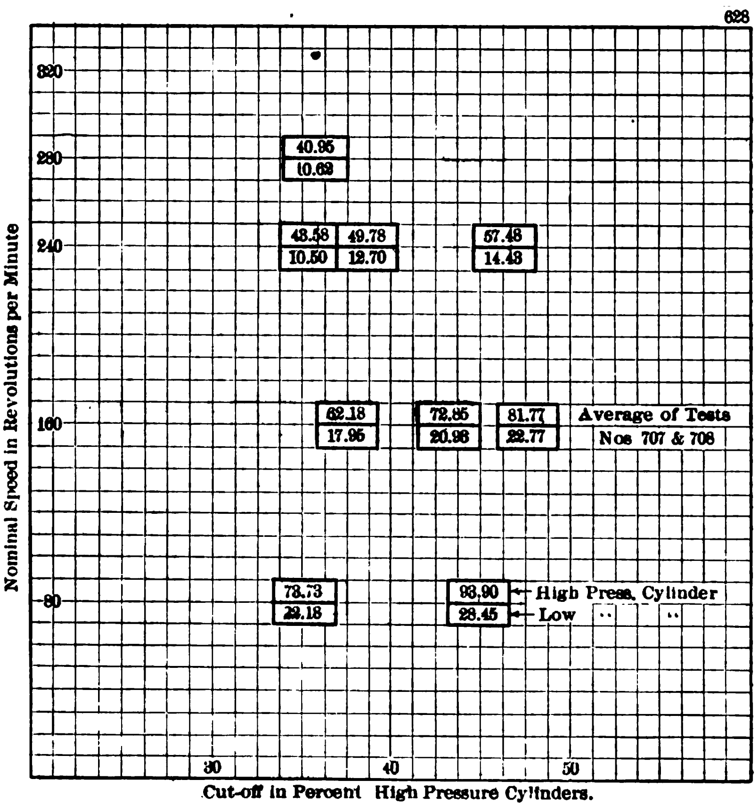


Fig. 706.—Mean Effective Pressures.

an hour, while the highest speed was 65.05 miles per hour. At this latter speed, while the dash-pots in the safety bars were put in operation to absorb the longitudinal vibrations of the locomotive, it was found their effect was practically neutralized by the vibration of the tail piece of the locomotive. This tail piece was built up of comparatively thin plates and angles, unlike the heavy rigid casting that is characteristic of American locomotives, and vibrated considerably when shocks were transmitted to it.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 710.

The best performance of the engine was at 43.2 per cent. high pressure cut-off and 160.06 revolutions per minute (about 37

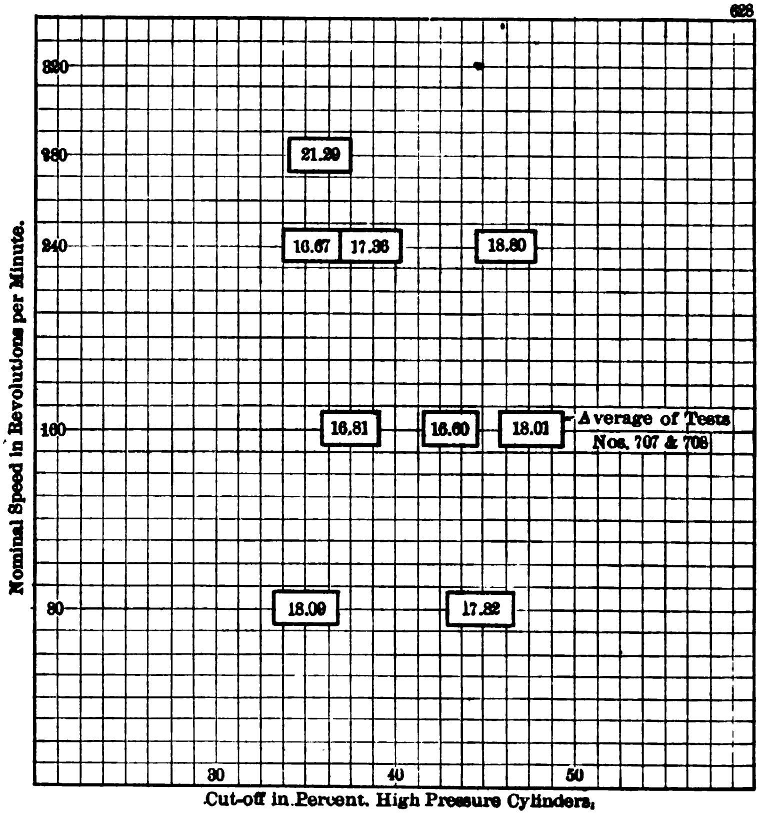


Fig. 707.— Superheated Steam per I. H. P. Hour.

miles per hour), under which conditions the steam consumption was 16.60 pounds of superheated steam per indicated horse power hour.

In order that the above statement may not be misleading, attention is here called to the fact that direct comparisons of the weight of steam consumed should not be made between this and the non-superheating locomotives. Superheated steam carries a greater quantity of energy per pound, in the form of heat units, than does dry and saturated steam of the same boiler pressure and it is, therefore, capable of doing more work in the engine

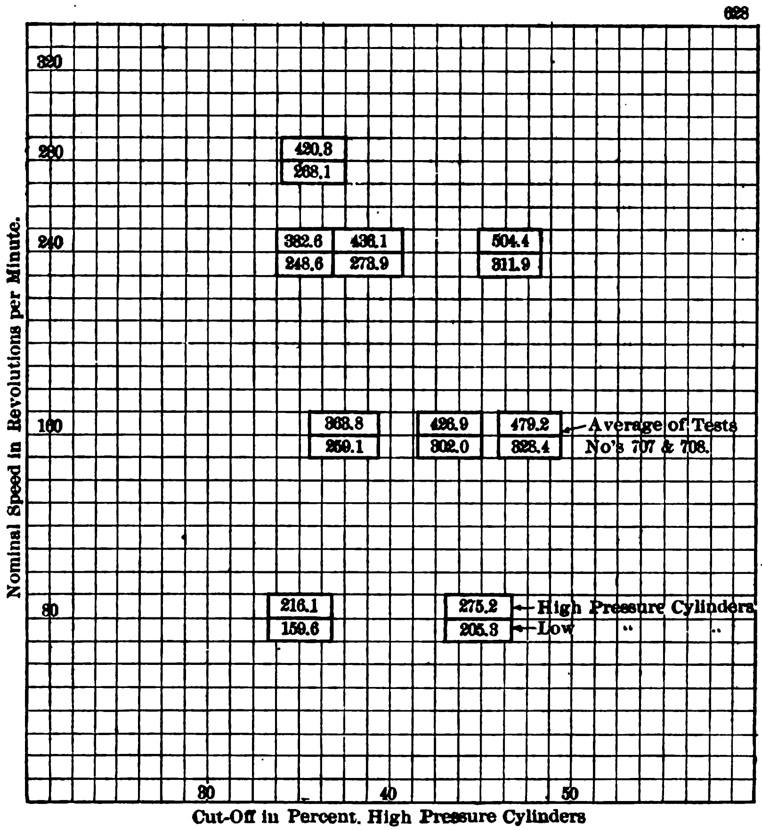


Fig. 708.—Total Indicated Horse Power.

than dry steam of the same pressure, provided the two kinds of steam are exhausted at nearly the same pressure. If we take for this same test the equivalent pounds of dry saturated steam supplied to the engine per hour and divide it by the horse power developed we obtain as the result 17.82 pounds of steam per horse power hour. The latter figure only gives an equivalent heat

TABLE No. 710—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test		Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch		Indicated Horse Power	Superheated Steam Per I. H. P. Hour, Lbs	Degrees of Superheat at Throttle.
Test Number	Laboratory Designation		H. P. Cyl.	L. P. Cyl.			
		Cal.	Cal.	Cal.	379	381	213
701	80-35-F	180	73.7	22.2	375.6	18.09	160.9
702	80-45-F	180	98.9	28.5	480.5	17.82	192.0
705	160-35-F	180	62.1	18.0	622.9	16.81	181.6
706	160-40-F	180	72.9	20.9	728.9	16.60	180.9
707	160-45-F	139.98	88.4	22.6	813.7	17.86	167.1
708	160-45-F	129.96	80.2	23.0	801.3	18.16	186.2
709	240-30-F	120	43.6	10.5	631.2	16.67	179.8
710	240-35-F	60	49.8	12.7	710.1	17.36	179.4
711	240-40-F	79.98	57.5	14.4	816.4	18.80	190.7
712	280-30-F	30	41.0	10.6	688.4	21.29	171.5

TABLE No. 711—DYNAMOMETER RECORDS.

Identification of Test		Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Superheated Steam Per D. H. P. Hour
Test Number	Laboratory Designation					
		Cal.	265	383	384	385
701	80-35-F	180	7186	358.3	2.60	19.23
702	80-45-F	180	9016	446.4	2.52	19.18
705	160-35-F	180	5552	549.8	2.57	19.04
706	160-40-F	180	6516	645.5	2.69	18.74
707	160-45-F	139.98	7622	754.5	3.40	19.26
708	160-45-F	129.96	6690	662.5	3.88	21.96
709	240-30-F	120	3624	538.4	2.80	19.54
710	240-35-F	60	4208	622.9	3.37	19.80
711	240-40-F	79.98	4339	644.4	5.31	23.81
712	280-30-F	30	3422	593.7	4.09	24.69

unit basis, as it cannot be said that the engines of this locomotive, under the specified conditions of speed and cut-off, would consume 17.82 pounds of saturated steam if the superheater were removed.

The highest indicated horse power was 816.4, which was obtained at 46.4 per cent. high pressure cut-off and a speed of 240 revolutions per minute.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 711.

The maximum average recorded draw-bar pull was 9,016

TABLE No. 712—MACHINE FRICTION.

Identification of Test		Duration of Test, Minutes	Machine Friction in		Machine Efficiency Per Cent.
Test Number	Laboratory Designation		Horse Power	Draw-Bar Pull Pounds	
		Cal.	395	397	398
701	80–35–F	180	22.29	450	94.08
702	80–45–F	180	34.10	689	92.91
	Average		**28.19**	**570**	
705	160–35–F	180	73.07	738	88.28
706	160–40–F	180	83.39	842	88.56
707	160–45–F	139.98	59.15	597	92.76
708	160–45–F	129.96	138.74	1401	82.68
	Average		**88.59**	**895**	
709	240–30–F	120	92.82	625	85.30
710	240–35–F	60	87.21	588	87.72
711	240–40–F	79.98	171.96	1158	78.94
	Average		**117.33**	**790**	
712	280–30–F	30	94.76	546	86.24

pounds at a speed of 80 revolutions per minute and a nominal high pressure cut-off of 45 per cent.

The maximum dynamometer horse power was 754.5, which was obtained at a speed of 160 revolutions per minute and a nominal high pressure cut-off of 45 per cent.

The general tendency was for the coal per dynamometer horse power hour to increase as the speed increased. The minimum coal rate obtained was 2.52 pounds and the maximum rate was 5.31 pounds of dry coal per dynamometer horse power hour.

The lowest steam consumption was 18.74 pounds of superheated steam per dynamometer horse power hour, which was obtained at a nominal speed of 160 revolutions per minute and a nominal high pressure cut-off of 40 per cent.

MACHINE FRICTION—TABLE 712.

The machine efficiency ranged from 78.94 per cent. to 94.08 per cent.

MAXIMUM POWER OF LOCOMOTIVE.

The maximum evaporative power of the boiler, as disclosed by these tests, was between 14,000 and 15,000 pounds of steam per hour, which is equivalent to a rate of evaporation of between 8 and 9 pounds per square foot of heating surface per hour.

The maximum draw-bar pull of this locomotive at the several speeds, as limited by the cylinder power and the maximum evaporation, is shown in Fig. 711. The method of obtaining this curve is explained in full in Chapter XIII, page 143.

The critical cut-offs, the steam consumption and the maximum cylinder horse power derived from Figs. 709 and 710 are given below:

NOMINAL SPEED IN R. P. M.	CUT-OFF IN PER CENT.	STEAM PER INDICATED H. P. HOUR.	MAXIMUM CYLINDER HORSE POWER
80	56.0	24.2	605
160	48.5	18.2	815
240	46.4	18.8	815
280	36.5	21.2	700

Reducing the maximum cylinder horse power to equivalent draw-bar pull and subtracting the average frictional draw-bar pull gives:

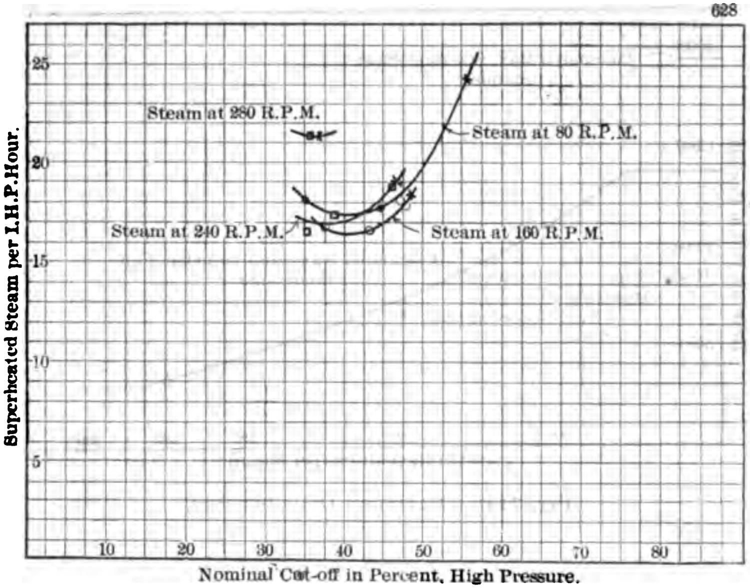


Fig. 709.—Steam Consumption.

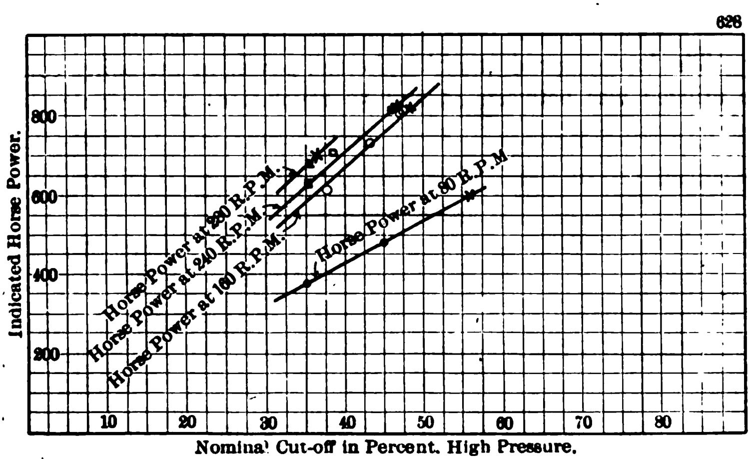


Fig. 710.—Indicated Horse Power.

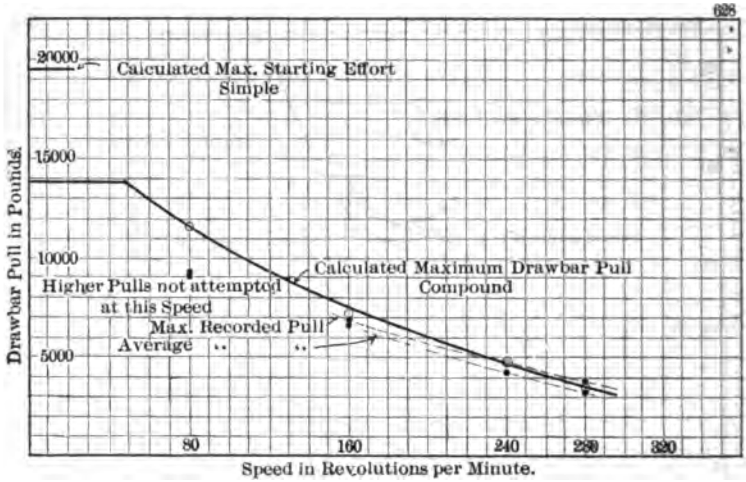


Fig. 711.—Maximum Draw-bar Pull.

SPEEDS IN R. P. M.	MAXIMUM ESTIMATED DRAW-BAR PULL. POUNDS.
80	11647
160	7336
240	4697
280	3492

The lowest speed at which the full power of the boiler could be utilized was between 45 and 50 revolutions per minute.

APPENDIX 700.

The appendix contains:

1. Description, dimensions and proportions of the locomotive. (pp. 564 to 569 inclusive.)

2. Summary of average results of tests. (pp. 570 to 581 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 582 to 586 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 587 to 602 inclusive.)

5. Vibration diagrams. (pp. 603 to 607 inclusive.)

6. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 608 to 611 inclusive.)

7. A typical dynamometer diagram for each nominal speed. (pp. 612 and 613.)

8. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of Hanover Locomotive Works S_8 Atlantic (4-4-2) Type Locomotive No. 628.

Built by the Hannoversche Maschinenbau-Actien-Gesellschaft, Linden vor Hannover Germany, 1904.

DRIVING WHEELS.

1	Number of pairs	2
2	Approximate diameter, inches	78

MEASURED CIRCUMFERENCE, FEET.

3	Right, No. 1	20.425
4	" " 2	20.420
5	" " 3	——
6	" " 4	——
7	" " 5	——
8	Left, " 1	20.423
9	" " 2	20.425
10	" " 3	——
11	" " 4	——
12	" " 5	——
13	Average	20.423

ENGINE TRUCK WHEELS.

14	Number	4
15	Diameter, inches	39.48

TRAILING WHEELS.

16	Diameter, inches	39.48

WHEEL BASE, FEET.

17	Driving wheel base	6.890
18	Total wheel base	29.540
19	Gauge of wheels, in inches	56.297

WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.

20	On truck	39,200
21	" 1st drivers	33,625
22	" 2nd "	31,725
23	" 3rd "	——
24	" 4th "	——
25	" 5th "	——
26	" trailers	28,800
27	Total	133,350
28	" on drivers	65,350

CYLINDERS.

29	High pressure, number	2
30	Low " "	2
31	Arrangement, L. P. outside; H. P. inside; Hanover.	

DIAMETER, INCHES.

32	High pressure, right	14.166
33	" " left	14.164
34	Low " right	22.048
35	" " left	22.078

STROKE OF PISTON, FEET.

36	High pressure, right	1.968
37	" " left	1.966
38	Low " right	1.969
39	" " left	1.969

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P., right, head end	12.8
41	" " crank "	11.5
42	" left, head "	11.9
43	" " crank "	10.7
44	L. P., right, head "	10.5
45	" " crank "	10.2
46	" left, head "	10.3
47	" " crank "	10.3

RECEIVER, CUBIC FEET.

48	Volume, right side	4.13
49	" left "	

STEAM PORTS, INCHES.

(For piston valves the length equals the circumference of inside of bushing minus the sum of the widths of bridges.)

50	H. P. admission, right, head end, length	15.52
51	" " " " " width	1.33
52	" " " crank " length	15.52
53	" " " " " width	1.33
54	" " left, head " length	15.36
55	" " " " " width	1.33
56	" " " crank " length	15.39
57	" " " " " width	1.33
58	L. P. " right, head " length	17.84
59	" " " " " width	1.97
60	" " " crank " length	17.84
61	" " " " " width	1.96
62	" " left, head " length	17.84
63	" " " " " width	1.97
64	" " " crank " length	17.84
65	" " " " " width	1.97
66	H. P. exhaust, right, length	17.34
67	" " " width	3.04
68	" " left, length	17.16
69	" " " width	3.04
70	L. P. " right, length	17.91

71	L. P. exhaust, right, width	2.74
72	" " left, length	17.91
73	" " " width	2.73

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	3.147
75	" " left	3.152
76	Low " right	2.755
77	" " left	2.753

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	" " left	——
80	Low " right	1.968
81	" " left	1.992

VALVES.

82 Type ....H. P. Piston; L. P. Allen—balanced.
83 Design, Hannoversche Maschinenbau Actien-Gesellschaft
84 Per cent. of balanced to total area.... H.P. 75.6; L.P. 44.7
85 Type of link motion, Heusinger von Waldegg-von Borries

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	5.063
87	" " left	4.938
88	Low " right	6.813
89	" " left	6.636

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure, right, head end	1.40
91	" " " crank "	1.40
92	" " left, head "	1.40
93	" " " crank "	1.40
94	Low " right, head "	1.37
95	" " " crank "	1.37
96	" " left, head "	1.37
97	" " " crank "	1.37

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	negative	.17
99	" " " crank "	"	.17
100	" " left, head "	"	.17
101	" " " crank "	"	.17
102	Low " right, head "	"	.02
103	" " " crank "	"	.02
104	" " left, head "	"	.01
105	" " " crank "	"	.01

MISCELLANEOUS.

106	Cylinder lagging material	hair
107	" jacket "	sheet iron
108	Lead, forward motion,	H. P., .12
109	" " "	L. P., .12
110	....	
111	Area of Allen Port L. P. Valve,	Sq. in. 7.96
112	....	Right L. P. crank leads left L. P. crank

BOILER.

113	Type	Straight top, wide fire box
114	Outside diameter, 1st ring, inches	62.24

TUBES.

115	Number	241
116	Outside diameter, inches	2
117	Thickness, inches	.098
118	Length between tube sheets, inches, not including superheater	143.78
119	Total fire area, square feet	2.50
120	Serve tubes, number of ribs	——
121	" " sq. in. of inside surface in one in. of length	——
122	....	
123	....	
124	Boiler pressure, pounds per sq. in.	200

SUPERHEATER.

125	Number of tubes	241.
126	Outside diameter, inches	2
127	Thickness, inches	.098
128	Length of tubes, inches between sheets	29.92
129	Type of Superheater	Pielock
130	....	
131	....	

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	55.13
133	Width	74.94
134	Depth, front end	57.48
135	" back "	57.00
136	Volume, cubic feet (less arch)	111.60
137	Air inlets to ash pan, (dampers closed) sq. ft	0.
138	" " " " " (" open) " "	3.32
139	....	
140	....	

FIRE DOORS.

141	Number	2
142	Area, square feet (of both)	2.18
143		

GRATES.

144	Style	stationary
145	Total area, square feet	29.06
146	" " dead grates, square feet	0
147	Width of air spaces, inches	.5

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	0
149	" grates	11.12
150	" fire doors	0
151	Total air inlets, (148), (149) and (150)	11.12
152	Ratio " " (149) to grate area (145)	.382
153	" " " (151) " " " (145)	.382

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	1511.94
155	" " " fire "	1363.77
156	" " firebox, fire side	105.59
157	" " superheater, fire side	283.79
158	Total, based on inside of firebox and inside of tubes, including superheater	1753.15
159	Total, based on inside of firebox and outside of tubes, including superheater	1932.16

BOILER VOLUMES.

(With water surface at level of second gauge cock.)

160	Water space, cubic feet	169.8
161	Steam " " " (incl. Superheater)	75.5

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	5.44 dia. with cross bar .7 in. wide
164	" " left, "	5.12 " " " " .7 " "
165	Area of right, square inches	
166	" " left, " "	
167	Total area, square inches,	first 19.44, second 17.01

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	39
169	L. P. " " " " "	(39, bracketed with 168)
170	Screw, reversing gear	

RATIOS.

171	Heating surface (158) to grate area (145)......	60.33
172	Fire area through tubes (119) to grate area (145)	.09
173	Firebox heating surface (156) to grate area (145)	3.63
174	Tube surface (155) to firebox heating surface (156)..	12.92
175	Firebox volume (136) to grate area (145)......	3.84
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(power developed at one R. P. M. when pull is one pound.)

179	....	.0006189

CONSTANTS FOR INDICATED HORSE POWER

(power developed at one R. P. M. and one pound M. E. P.)

180	High pressure cylinder, right, head end	.009399
181	" " " " crank "	.008935
182	" " " left, head "	.009387
183	" " " " crank "	.008922
184	Low " " right, head "	.022598
185	" " " " crank "	.022425
186	" " " left, head "	.022656
187	" " " " crank "	.022488

PISTON DISPLACEMENT, CUBIC FEET.

188	High pressure cylinder, right, head end	2.1539
189	" " " " crank "	2.0475
190	" " " left, head "	2.1511
191	" " " " crank "	2.0446
192	Low " " right, head "	5.1786
193	" " " " crank "	5.1389
194	" " " left, head "	5.1918
195	" " " " crank "	5.1534

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed				Position of Levers			Coal Loss due to Steam Loss Lbs. Per Hour	Temperature of Steam in Superheater, Degrees F.
			Revolutions		Equivalent						
			Total	Average Per Minute	Speed in Miles Per Hour	Piston Speed in Feet Per Minute	Reverse, Notches From Front End	Area of Exhaust Nozzle Sq. Inches	Throttle Notches		
		196	197	198	199	200	201	202	203	204	205
701	80-35-F	3.000	14400	80.00	18.57	314.9	21	19.44	FULL	79.	550.4
702	80-45-F	3.000	14400	80.00	18.57	314.9	16	19.44	"	80	581.0
705	160-35-F	3.000	28800	160.00	37.13	629.7	21	19.44	"	109	570.8
706	160-40-F	3.000	28811	160.06	37.15	630.0	19	19.44	"	99	570.2
707	160-45-F	2.333	22400	160.00	37.13	629.7	16	19.44	"	116	556.7
708	160-45-F	2.166	20800	160.00	37.13	629.7	16	17.01	"	82	572.0
709	240-30-F	2.000	28800	240.00	55.70	944.7	23	19.44	"	88	568.4
710	240-35-F	1.000	14366	239.43	55.57	942.4	21		"	65	562.6
711	240-40-F	1.333	19200	240.00	55.70	944.7	18	17.01	"	103	572.4
712	280-30-F	.500	8408	280.27	65.05	1103.1	23	17.01	"	98	560.1

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of								Horizontal Vibration at Front of Engine Inches		Steam lost from Boiler, etc. Lbs. per hour
		Smoke Box		Laboratory								
		By Thermometer	By Pyrometer	Dry Bulb	Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer	Superheat in Superheater			
		206	207	208	209	210	211	212	213	214	215	216
701	80-35-F	547	561	59.2	52.0	469.9	55.6	2049	160.9	——		583
702	80-45-F	571	597	64.7	54.8	473.9	58.8	2108	192.0	——		612
705	160-35-F	600	629	55.7	49.6	467.6	55.7	2110	181.6	.085		812
706	160-40-F	636	670	51.8	45.0	490.6	56.1	2118	180.9	.100		691
707	160-45-F	701	707	55.2	47.6	501.3	53.8	2253	167.1	.095		660
708	160-45-F	——	709	37.5	33.3	483.5	52.1	2062	186.2	——		464
709	240-30-F	595	651	44.9	40.9	563.8	54.5	1950	179.8	.250		616
710	240-35-F	631	639	48.0	43.4	465.4	53.8	2118	179.4	.170		381
711	240-40-F	742	787	45.8	39.5	480.9	53.6	2048	190.7	.175		461
712	280-30-F	——	676	45.9	38.3	457.6	52.0	2043	171.5	.500		589

For date of test, see item 407.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch					Draft, Inches of Water				Injectors	
		In Boiler			In Branch Pipe	Air in Laboratory Barometric	In Smoke Box		In Fire Box	In Ash Pan	Hours in Action	
		Average	Maximum	Minimum							Total, Right	Total, Left
		217	218	219	220	221	222	223	224	225	226	227
701	80-35-F	198.8	204.8	194.0	194.6	14.443	.88		.56	.19	0	.839
702	80-45-F	202.0	205.0	198.8	198.3	14.425	1.29		.68	.17	0	.973
705	160-35-F	198.8	206.1	186.1	194.4	14.462	1.69		.81	.19	0	1.154
706	160-40-F	202.6	206.5	200.2	197.4	14.481	2.22		1.09	.21	0	1.898
707	160-45-F	198.8	207.0	184.3	193.6	14.443	2.94		1.22	.24	0	1.283
708	160-45-F	197.0	203.4	145.0	190.9	14.534	3.57		1.82	.38	0	1.080
709	240-30-F	204.1	206.5	203.1	198.5	14.540	1.70		1.02	.12	0	.891
710	240-35-F	191.1	205.6	143.9	185.1	14.393	2.17		1.55	.21	0	.458
711	240-40-F	187.0	205.5	184.1	179.9	14.651	3.70		1.86	.22	0	.859
712	280-30-F	204.2	209.5	201.0	196.6	14.455	3.50		1.17	.29	0	.228

Test Number	Laboratory Designation	Quality of steam				Coal, Sparks and Ash, Pounds					
						Coal Fired			Total		
		In Dome	In Branch Pipe	Degrees of Superheat in Branch Pipe	Factor of Correction Superheater	Kind	Total	Per Cent of Moisture	Dry Coal Fired	Combustible by Analysis	Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
701	80-35-F	.9984	1.0482	84.45	1.06543	Bituminous	3021	1.00	2991	2860	131
702	80-45-F	.9968	1.0497	86.97	1.07784	"	3653	.95	3618	3408	211
705	160-35-F	.9949	1.0469	82.18	1.07385	"	4605	.93	4562	4324	237
706	160-40-F	.9978	1.0594	108.98	1.07354	"	5562	1.17	5497	5182	315
707	160-45-F	.9986	1.0663	116.20	1.06918	"	6310	.96	6249	5864	385
708	160-45-F	.9956	1.0554	97.19	1.07581	"	5812	1.12	5747	5393	353
709	240-30-F	.9969	1.0505	88.36	1.07327	"	3225	1.25	3185	2948	236
710	240-35-F	.9979	1.0477	88.87	1.07316	"	2191	1.17	2165	2025	140
711	240-40-F	.9977	1.0576	101.46	1.07773	"	4745	1.00	4698	4284	463
712	280-30-F	.9936	1.0407	71.28	1.06974	"	1279	1.29	1262	1186	762

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs — Total: Cinders Collected in Smoke Box	Sparks Discharged From Stack	Cinders and Sparks	Analysis of Coal — Per Cent: Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
701	80-35-F	209	251	460	78.20	16.49	1.00	4.31	.92		
702	80-45-F	165	32	197	76.03	17.25	.95	5.77	.83		
705	160-35-F	286	30	316	77.54	16.37	.93	5.16	.81		
706	160-40-F	434	37	471	76.43	16.74	1.17	5.66	.68		
707	160-45-F	1018	125	1143	76.76	16.18	.96	6.10	.92		
708	160-45-F	920	91	1011	76.32	16.48	1.12	6.08	.69		
709	240-30-F	224	39	263	75.40	15.93	1.25	7.32	.62		
710	240-35-F	340	53	393	76.33	16.10	1.17	6.40	.67		
711	240-40-F	809	150	959	72.76	16.48	1.00	9.76	.98		
712	280-30-F	——	——	——	76.26	16.49	1.29	5.96	.83		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B. T. U.: Of Dry Coal	Of Combustible	Of Cinders	Of Sparks		Analysis of Smoke Box Gases — Per Cent: Oxygen O	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
701	80-35-F	15082	15769	13225	12799		9.93	.17	8.83	81.07		
702	80-45-F	15182	16120	12585	12165		9.33	1.20	8.47	81.00		
705	160-35-F	15071	15900	13225	12372		6.43	.60	11.47	81.50		
706	160-40-F	15108	16026	13438	11945		8.40	.47	10.20	80.93		
707	160-45-F	15076	16065	12799	11732		4.73	1.57	11.33	82.37		
708	160-45-F	14994	15975	13225	12799		4.43	3.30	10.93	81.34		
709	240-30-F	14905	16098	13225	12799		6.30	.57	11.77	81.36		
710	240-35-F	15108	16154	13438	13225		6.15	2.30	10.05	81.50		
711	240-40-F	14436	16003	13652	13225		8.93	1.73	7.97	81.37		
712	280-30-F	15018	15983	——	——		4.30	4.00	10.30	81.40		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Water, in Pounds						Dynamometer		
			Lost					Drawbar Pull in Pounds		
		Delivered to Injectors	From Boiler	From Injectors	From	Total	Delivered to Boiler and Presumably Evaporated	Average	Maximum	Minimum
		259	260	261	262	263	264	265	266	267
701	80–35–F	29899	0	7765		7765	22134	7136	7302	6753
702	80–45–F	32098	0	4564		4564	27529	9016	9205	8810
705	160–35–F	40469	0	6624		6624	33845	5552	5921	4988
706	160–40–F	39169	0	804		804	38365	6516	6652	6161
707	160–45–F	39169	0	3723		3723	35446	7622	8254	4837
708	160–45–F	32697	0	174		174	32523	6690	6931	5493
709	240–30–F	22582	0	308		308	22274	3624	3878	3459
710	240–35–F	12745	0	35		35	12710	4203	4520	3323
711	240–40–F	21068	0	0		0	21068	4339	4729	3560
712	280–30–F	7622	0	0		0	7622	3422	3847	3138

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Cut-off, Per Cent. of Stroke								Release, Per Cent. of Stroke			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
701	80–35–F	38.3	33.3	34.9	34.2	53.4	53.7	52.0	53.7	75.6	70.0	72.7	70.6
702	80–45–F	48.1	42.7	45.1	43.5	63.7	62.1	62.9	62.9	82.2	75.0	79.6	76.3
705	160–35–F	41.2	35.1	36.4	37.7	53.2	55.5	52.7	54.7	75.3	69.6	71.4	71.8
706	160–40–F	47.2	40.6	42.1	42.7	59.4	60.9	58.6	60.4	76.5	72.2	73.2	73.6
707	160–45–F	50.3	47.3	45.5	48.2	66.1	66.6	65.7	65.9	76.9	76.0	79.5	77.7
708	160–45–F	50.1	46.0	46.1	47.4	64.2	65.4	64.9	65.5	78.9	77.1	81.0	79.2
709	240–30–F	36.9	33.4	35.6	35.1	50.8	51.9	48.1	51.2	71.4	64.4	64.2	69.1
710	240–35–F	41.7	36.7	37.0	39.5	53.8	55.7	53.1	55.7	76.5	73.2	77.3	75.8
711	240–40–F	48.9	44.7	44.4	47.5	62.7	65.1	62.8	64.3	80.5	75.2	79.1	76.6
712	280–30–F	38.0	34.3	34.0	37.0	51.8	55.9	52.2	52.9	75.0	71.3	71.2	75.9

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
701	80-35-F	83.7	81.9	83.6	82.0	29.2	28.2	29.1	27.7	23.5	18.8	23.2	13.0
702	80-45-F	89.1	85.6	87.9	86.6	24.6	24.7	24.3	21.8	17.0	11.9	17.0	9.0
705	160-35-F	81.7	80.7	80.0	81.6	32.1	25.4	30.8	27.8	25.7	22.4	27.6	24.1
706	160-40-F	82.9	83.4	82.3	82.9	33.9	25.7	31.1	25.2	22.6	18.7	24.9	20.6
707	160-45-F	88.9	86.0	87.3	86.5	26.5	21.4	28.9	21.6	19.0	14.8	20.3	15.5
708	160-45-F	88.2	87.0	88.1	87.1	30.3	22.9	27.0	21.5	18.9	15.6	20.3	15.3
709	240-30-F	82.1	79.7	74.0	74.9	37.8	31.2	35.8	33.2	33.2	29.7	32.9	30.6
710	240-35-F	79.0	78.8	77.7	78.2	37.8	26.5	32.8	26.7	28.3	22.8	27.5	23.7
711	240-40-F	84.4	85.0	83.2	83.4	32.9	24.7	33.3	22.6	25.4	20.8	27.1	21.6
712	280-30-F	78.6	83.0	76.0	77.0	42.0	30.0	31.6	31.3	31.3	28.4	31.7	28.8

Test Number	Laboratory Designation	Pressures from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
701	80-35-F	201.9	196.8	192.6	191.4	40.3	36.8	36.5	35.6	1.2160
702	80-45-F	203.6	200.4	192.8	196.5	47.8	43.6	42.4	41.5	1.2131
705	160-35-F	196.7	191.1	185.8	193.6	43.2	38.5	38.3	41.3	1.2150
706	160-40-F	198.2	201.7	187.2	201.3	45.7	38.8	41.7	44.1	1.2160
707	160-45-F	195.5	198.6	180.2	197.2	45.7	37.9	40.6	43.4	1.2181
708	160-45-F	192.0	194.6	184.6	193.4	51.1	43.4	43.5	48.5	1.2210
709	240-30-F	204.9	200.3	201.5	207.5	41.4	38.4	42.5	42.5	1.2230
710	240-35-F	196.7	197.7	196.7	203.7	40.1	36.6	42.2	40.3	1.2220
711	240-40-F	179.3	190.2	174.5	180.2	38.0	38.2	37.3	41.0	1.2230
712	280-30-F	207.0	188.6	200.3	194.0	58.7	47.1	53.8	55.6	1.2210

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Pressures from Indicator Cards								
		Steam Chest Pressures, Pounds Per Square Inch					Pressures at Cut-off, Pounds Per Square Inch			
		High Pressure		Low Pressure			High Pressure Cylinder			
							Right Side		Left Side	
		Right Side	Left Side	Right Side	Left Side		Head End	Crank End	Head End	Crank End
		301	302	303	304	305	306	307	308	309
701	80-35-F	202.9		38.9			162.4	156.6	144.9	161.8
702	80-45-F	203.8		46.3			169.6	164.6	156.8	169.5
705	160-35-F	201.5		40.8			135.5	134.4	124.8	133.9
706	160-40-F	202.8		40.4			133.4	134.7	126.3	136.4
707	160-45-F	195.5		——			136.0	139.9	136.0	139.1
708	160-45-F	194.8		42.7			140.4	136.3	133.4	139.7
709	240-30-F	205.3		36.5			116.5	117.6	116.6	112.6
710	240-35-F	197.7		35.6			117.0	114.5	104.0	110.6
711	240-40-F	179.6		36.8			111.6	111.5	107.8	108.7
712	280-30-F	——		43.4			112.0	108.0	104.6	115.0

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Cut-off, Pounds Per Square Inch				Pressures at Release, Pounds Per Square Inch							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
701	80-35-F	26.7	26.5	24.5	27.8	98.3	84.5	75.9	82.7	13.7	14.0	11.5	14.7
702	80-45-F	30.5	30.8	28.7	31.4	102.6	97.4	92.8	97.9	18.8	19.5	17.4	19.6
705	160-35-F	23.3	22.4	20.9	22.4	80.6	78.2	68.1	73.2	11.9	12.4	10.4	12.6
706	160-40-F	24.8	22.7	22.8	24.2	84.9	80.4	78.3	82.1	14.7	14.3	13.6	15.6
707	160-45-F	24.5	21.1	23.7	25.2	90.6	88.2	80.2	86.1	15.7	14.8	15.7	17.1
708	160-45-F	27.2	24.7	25.8	26.5	90.7	85.4	79.7	86.4	17.2	16.0	16.0	17.4
709	240-30-F	17.7	18.0	16.5	18.2	64.8	64.4	60.6	57.7	7.6	9.5	8.2	9.9
710	240-35-F	19.1	19.5	16.6	19.3	62.8	60.7	51.7	59.7	9.7	11.8	8.8	11.2
711	240-40-F	20.7	19.6	18.6	19.9	65.9	68.0	60.3	66.4	12.8	13.0	10.8	13.4
712	280-30-F	16.0	19.5	16.1	19.7	58.0	59.3	56.0	57.3	9.1	10.0	8.1	10.7

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Beginning of Compression, Pounds Per Square Inch								Least Back Pressure, Pounds Per Square Inch			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
701	80-35-F	51.6	41.4	44.1	39.0	1.3	1.2	1.2	1.6	45.4	37.5	34.1	37.2
702	80-45-F	48.9	41.4	45.1	40.3	1.0	1.0	1.1	1.5	42.9	38.6	35.9	38.4
705	160-35-F	48.9	43.1	45.6	41.3	2.9	3.1	3.5	3.8	42.9	39.1	35.3	38.5
706	160-40-F	44.9	44.8	45.7	43.0	4.2	3.7	4.2	4.4	39.6	40.3	37.8	40.8
707	160-45-F	39.5	42.5	42.2	41.2	4.7	3.8	5.0	5.5	35.5	39.9	36.5	39.0
708	160-45-F	45.7	44.6	46.3	44.3	5.9	5.9	6.3	6.6	40.8	42.4	39.7	43.1
709	240-30-F	44.8	44.2	41.1	42.3	4.5	5.3	5.4	5.8	38.8	39.9	37.6	39.5
710	240-35-F	44.0	44.0	46.0	43.0	5.5	6.8	6.7	7.3	38.8	40.0	35.7	40.0
711	240-40-F	42.9	40.8	42.2	42.1	8.1	8.0	8.0	9.1	38.4	38.4	37.3	40.1
712	280-30-F	53.0	52.6	51.3	54.0	7.0	8.8	8.6	9.3	48.0	44.3	41.0	44.0

Test Number	Laboratory Designation	Pressures from Indicator Cards				Boiler					
		Least Back Pressure, Pounds Per Square Inch				Dry Coal Fired Pounds		Evaporation, Pounds			
		Low Pressure Cylinder						Steam Per Hour			Steam Per Pound of Dry Coal Fired
		Right Side		Left Side		Per Hour	Per Hour Per Square Foot of Grate Surface	Moist	Dry	Per Sq. Ft. of Heating Surface	
		Head End	Crank End	Head End	Crank End						
		334	335	336	337	338	339	340	341	342	343
701	80-35-F	1.0	1.0	.8	1.5	997	34.31	7378		4.208	7.401
702	80-45-F	.9	1.0	1.0	1.5	1206	41.51	9176		5.234	7.607
705	160-35-F	1.7	2.0	2.0	2.7	1521	52.33	11282		6.436	7.420
706	160-40-F	2.1	2.5	2.3	3.4	1882	63.06	12788		7.294	6.979
707	160-45-F	2.7	3.0	3.3	4.0	2679	92.18	15193		8.667	5.673
708	160-45-F	4.1	4.1	3.8	4.9	2653	91.29	15014		8.565	5.660
709	240-30-F	2.0	2.2	1.8	2.9	1592	54.80	11187		6.353	6.995
710	240-35-F	2.7	2.8	2.0	3.3	2165	74.51	12710		7.250	5.870
711	240-40-F	5.0	5.2	4.7	6.2	3523	121.30	15804		9.015	4.485
712	280-30-F	4.0	4.0	4.0	5.1	2525	86.88	15244		8.697	6.039

For steam lost from boiler and not delivered to engines, see item 216.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

Hannoversche Maschinenbau-Actien-Gesellschaft.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Boiler: Equiv't Evap'n: Per Hour, Per Sq. Ft. of Heat. Surface	Boiler: Equiv't Evap'n: Per Pound of Coal as Fired	Per Pound of Dry Coal as Fired	Per Pound of Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		344	345	346	347	348	349	350	351	352	353	354
701	80-35-F	9560	5.45	9.50	9.57	10.00	277.1	61.22	76.8	73.6	67.6	76.9
702	80-45-F	12000	6.85	9.86	9.95	10.57	347.9	63.30	97.9	91.8	90.9	95.0
705	160-35-F	14720	8.40	9.59	9.68	10.21	426.7	62.03	64.6	63.2	55.1	65.6
706	160-40-F	16696	9.52	9.01	9.11	9.67	484.0	58.28	74.9	73.4	66.8	76.3
707	160-45-F	19789	11.29	7.32	7.39	7.87	573.6	47.33	85.4	83.9	78.2	85.9
708	160-45-F	19725	11.25	7.35	7.49	7.92	571.8	48.22	81.5	79.4	76.0	83.8
709	240-30-F	14620	8.34	9.07	9.18	9.92	423.8	59.49	44.5	45.0	38.6	46.2
710	240-35-F	16670	9.51	7.61	7.70	8.23	483.2	49.22	50.6	53.0	42.3	53.2
711	240-40-F	20834	11.88	5.85	5.91	6.56	603.9	39.55	57.7	60.4	51.2	60.6
712	280-30-F	19913	11.36	7.79	7.89	8.39	577.2	50.73	45.1	38.5	34.8	45.4

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square Inch: Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Receiver Pressure: Right Side	Receiver Pressure: Left Side	Number of Expansions: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		355	356	357	358	359	360	361	362	363	364
701	80-35-F	22.2	22.8	20.0	23.7			4.43	5.15	4.85	5.18
702	80-45-F	28.9	29.2	26.2	29.5			3.93	4.43	4.16	4.51
705	160-35-F	18.0	19.2	15.6	19.0			4.11	4.89	4.52	4.79
706	160-40-F	21.1	21.8	18.9	21.9			3.74	4.51	4.14	4.40
707	160-45-F	22.2	23.4	21.0	23.6			3.79	4.10	4.11	4.14
708	160-45-F	22.5	23.1	22.2	24.1			3.77	4.24	4.09	4.23
709	240-30-F	11.3	12.9	10.0	7.8			4.43	5.02	4.29	4.69
710	240-35-F	12.6	13.9	10.9	13.4			4.55	5.12	4.90	5.26
711	240-40-F	14.4	15.3	13.1	14.9			3.70	4.25	4.01	4.06
712	280-30-F	11.1	11.8	8.4	11.2			4.22	5.10	4.54	4.62

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
701	80-35-F	57.8	52.6	50.8	54.9	40.0	40.8	36.2	42.6	110.4	105.7	80.9	78.7
702	80-45-F	73.6	65.6	68.2	67.8	52.2	52.3	47.6	53.1	139.2	136.0	104.6	100.7
705	160-35-F	97.1	90.4	82.7	93.6	65.2	68.7	56.7	68.5	187.5	176.3	133.9	125.2
706	160-40-F	112.7	105.0	100.4	109.0	76.4	78.1	68.6	78.8	217.6	209.3	154.6	147.4
707	160-45-F	128.5	120.0	117.5	122.6	80.3	83.9	76.2	84.7	248.5	240.1	164.2	160.9
708	160-45-F	122.5	113.5	114.1	119.6	81.5	82.9	80.4	86.9	236.0	233.7	164.3	167.3
709	240-30-F	100.4	96.4	87.0	98.8	61.2	69.4	54.4	63.6	196.8	185.8	130.6	118.0
710	240-35-F	113.9	113.4	95.2	113.7	68.2	74.5	59.0	72.3	227.3	208.8	142.7	131.2
711	240-40-F	130.0	129.4	115.3	129.7	78.0	82.2	71.3	80.5	259.4	245.0	160.1	151.8
712	280-30-F	118.8	96.4	91.6	113.4	70.1	74.4	53.3	70.4	215.2	205.1	144.4	123.7

Test Number	Laboratory Designation	Engines						Locomotive			
		Division of Power			Consumed Per I. H. P., Hour			Dynamometer Horse Power	Pounds Per D. H. P., Hour		B. T. U. Per D. H. P., Hour
		Total									
		Right Side	Left Side	Total I. H. P.	Dry Coal, Pounds	Superhea'd Steam, Pounds	B. T. U.		Of Dry Coal	Of Superhea'd Steam	
		377	378	379	380	381	382	383	384	385	386
701	80-35-F	191.2	184.4	375.6	2.44	18.09	36860	353.3	2.60	19.23	39180
702	80-45-F	243.8	236.7	480.5	2.34	17.82	35580	446.4	2.52	19.18	38301
705	160-35-F	321.4	301.5	622.9	2.27	16.81	34156	549.8	2.57	19.04	38705
706	160-40-F	372.2	356.7	728.9	2.38	16.60	35934	645.5	2.69	18.74	40590
707	160-45-F	412.7	401.0	813.7	3.15	17.86	47481	754.5	3.40	19.26	51208
708	160-45-F	400.3	401.0	801.3	3.21	18.16	48123	662.5	3.88	21.96	58193
709	240-30-F	327.4	303.8	631.2	2.38	16.67	35530	538.4	2.80	19.54	41650
710	240-35-F	370.0	340.1	710.1	2.96	17.36	44689	622.9	3.37	19.80	50949
711	240-40-F	419.6	396.8	816.4	4.19	18.80	60478	644.4	5.31	23.81	76613
712	280-30-F	359.7	328.8	688.4	3.53	21.29	52959	593.7	4 09	24.69	61492

For Maximum Indicated Horse Power, see item 403.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Locomotive										
		Per One Million Foot Pounds at Draw-Bar			I. H. P. Per Square Foot of		D. H. P. Per Square Foot of		Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of		
		Dry Coal, Pounds	Superhea'd Steam, Pounds	B. T. U.	Heating Surface	Grate Surface	Heating Surface	Grate Surface		Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
701	80-35-F	1.31	9.71	19797	.2142	12.92	.2015	12.16	7586	22.29		450
702	80-45-F	1.27	9.69	19349	.2741	16.53	.2546	15.36	9705	34.10		689
705	160-35-F	1.30	9.62	19548	.3553	21.44	.3136	18.92	6290	73.07		738
706	160-40-F	1.36	9.47	20481	.4157	25.08	.3682	22.21	7358	83.39		842
707	160-45-F	1.71	9.72	25848	.4641	28.00	.4305	25.97	8216	59.15		597
708	160-45-F	1.96	11.09	29382	.4570	27.57	.3779	22.80	8091	138.74		1401
709	240-30-F	1.41	9.87	21042	.3600	21.72	.3071	18.53	4248	92.82		625
710	240-35-F	1.70	10.00	25730	.4050	24.43	.3553	21.44	4784	87.21		588
711	240-40-F	2.69	12.05	38767	.4660	28.09	.3675	22.17	5501	171.96		1158
712	280-30-F	2.07	12.47	31016	.3930	23.69	.3386	20.43	3968	94.76		546

Test Number	Laboratory Designation	Locomotive		Ratios							
		Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
701	80-35-F	94.08	6.50	350.1	4.60	700	380.9				11-4-04
702	80-45-F	92.91	6.65	273.8	3.60	884	487.0				11-4-04
705	160-35-F	88.28	6.58	209.0	2.75	1089	638.1				11-5-04
706	160-40-F	88.56	6.27	181.6	2.39	1278	784.5				11-8-04
707	160-45-F	92.76	4.97	154.5	2.03	1496	862.9				11-7-04
708	160-45-F	82.68	4.37	159.9	2.10	1312	833.9				11-12-04
709	240-30-F	85.30	6.11	204.3	2.69	1066	652.8				11-10-04
710	240-35-F	87.72	5.00	175.4	2.31	1233	760.1				11-9-04
711	240-40-F	78.94	3.32	143.1	1.88	1273	931.9				11-11-04
712	280-30-F	86.24	4.14	188.4	2.48	1176	707.9				11-12-04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628

HANNOVERSCHE MASCHINENBAU-ACTIEN-GESELLSCHAFT.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Superheat in Superheater	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft, in Smokebox Inches of Water	Dry Coal Fired Per Hour, Pounds	Superheated Steam Used Per Hour, Pounds
		196	198	199	268 to 271	213	217	220	222	333	341
701	80-35-F	3.00	80.00	18.57	35.2	160.9	198.3	194.6	.88	997	7378
702	80-45-F	3.00	80.00	18.57	44.9	192.0	202.0	198.3	1.29	1206	9176
705	160-35-F	3.00	160.00	37.13	37.6	181.6	198.8	194.4	1.69	1521	11282
706	160-40-F	3.00	160.06	37.15	43.2	180.9	202.6	197.4	2.22	1832	12788
707	160-45-F	2.33	160.00	37.13	47.8	167.1	198.8	193.6	2.94	2679	15193
708	160-45-F	2.17	160.00	37.13	47.4	186.2	197.0	190.9	3.57	2653	15014
709	240-30-F	2.00	240.00	55.70	35.3	179.8	204.1	198.5	1.70	1592	11137
710	240-35-F	1.00	239.43	55.57	38.8	179.4	191.1	185.1	2.17	2165	12710
711	240-40-F	1.33	240.00	55.70	46.4	190.7	187.0	179.9	3.70	3523	15804
712	280-30-F	.50	280.27	65.05	35.8	171.5	204.2	196.6	3.50	2525	15244

Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Superheated Steam Per I. H. P. Hour, Pounds	Superheated Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		347	379	383	395	265	380	384	381	385	350	390
701	80-35-F	9.57	375.6	353.3	22.29	7136	2.44	2.60	18.09	19.23	61.22	6.50
702	80-45-F	9.95	480.5	446.4	34.10	9016	2.34	2.52	17.82	19.18	63.30	6.65
705	160-35-F	9.68	622.9	549.8	73.07	5552	2.27	2.57	16.81	19.04	62.03	6.58
706	160-40-F	9.11	728.9	645.5	83.39	6516	2.38	2.69	16.60	18.74	58.28	6.27
707	160-45-F	7.39	813.7	754.5	59.15	7622	3.15	3.40	17.86	19.26	47.33	4.97
708	160-45-F	7.49	801.3	662.5	138.74	6690	3.21	3.88	18.16	21.96	48.22	4.37
709	240-30-F	9.18	631.2	538.4	92.82	3624	2.38	2.80	16.67	19.54	59.49	6.11
710	240-35-F	7.70	710.1	622.9	87.21	4203	2.96	3.37	17.[illegible]	19.80	49.22	5.00
711	240-40-F	5.91	816.4	644.4	171.96	4339	4.19	5.31	18.80	23.81	39.55	3.33
712	280-30-F	7.89	688.4	593.7	94.76	3422	3.53	4.09	21.29	24.69	50.73	4.14

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

Hannoversche Maschinenbau-Actien-Gesellschaft.

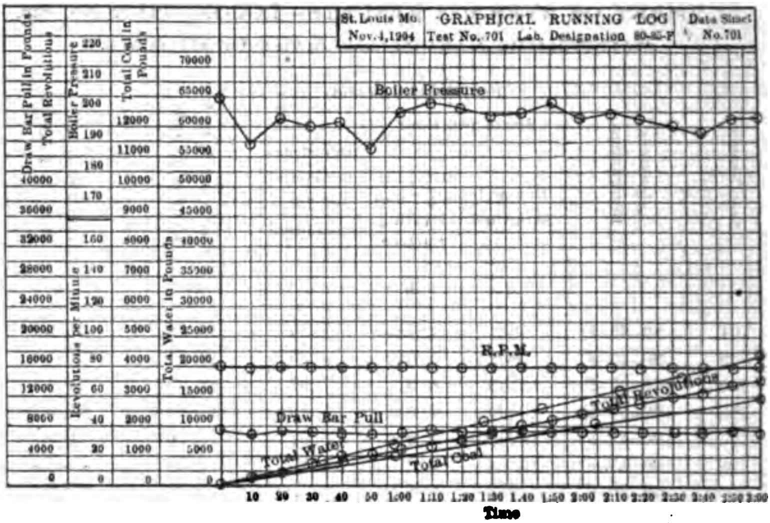
Test Number	Laboratory Designation	Evaporation, Pounds: Steam per Hour: Dry and Saturated	Evaporation, Pounds: Steam per Hour: Dry, Per Sq. Ft. of Heating Surface	Evaporation, Pounds: Dry Steam Per Pound of Dry Coal Fired	Steam per I. H. P. Hour in Pounds	Steam Per D. H. P. Hour in Pounds
		A	B	C	D	E
701	80-35-F	7861	4.484	7.89	19.28	20.49
702	80-45-F	9892	5.642	8.20	19.21	20.68
705	160-35-F	12115	6.911	7.97	18.05	20.45
706	160-40-F	13780	7.881	7.49	17.82	20.12
707	160-45-F	16244	9.266	6.07	19.10	20.60
708	160-45-F	16154	9.215	6.13	19.54	23.63
709	240-30-F	11953	6.818	7.51	17.89	20.98
710	240-35-F	13641	7.780	6.30	18.63	21.24
711	240-40-F	17034	9.717	4.84	20.26	25.66
712	280-30-F	16308	9.302	6.46	22.77	26.41

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 628.

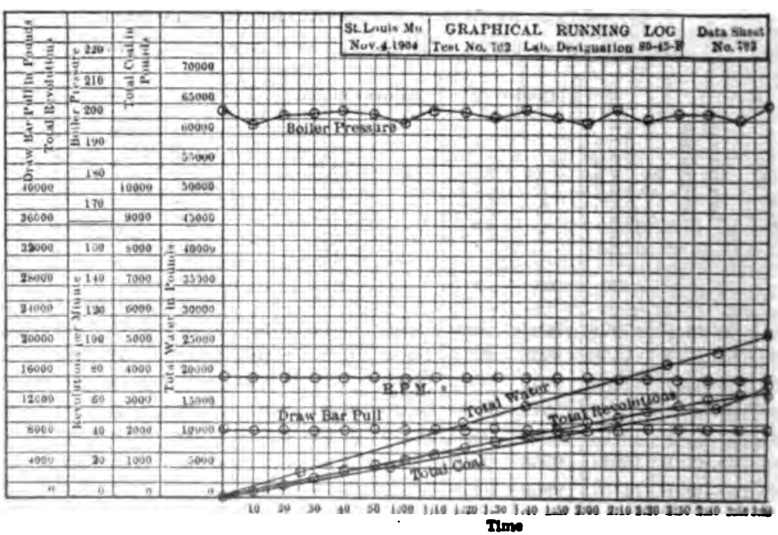
Hannoversche Maschinenbau-Actien-Gesellschaft.

(Items based on quality of steam BEFORE entering superheater.)

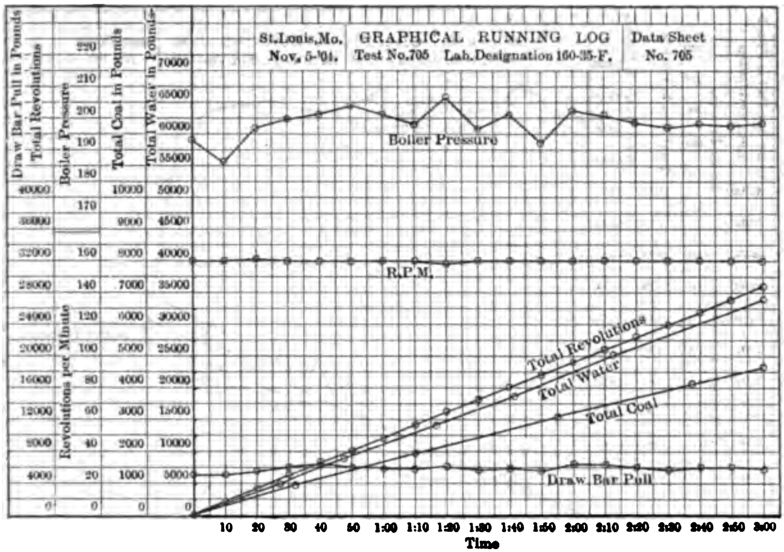
Test Number	Laboratory Designation	Moist Steam Evaporated per Hour, Pounds	Quality of Steam: In Dome	Quality of Steam: Factor of Correction in Dome	Equivalent Evaporation from and at 212° F, Pounds: Per Hour	Per Hour, per Square Foot of Heating Surf.	Per Pound of: Coal as Fired	Per Pound of: Dry Coal as Fired	Per Pound of: Combustible	Boiler Horse Power	Efficiency of Boiler
		340	228	F	G	H	I	J	K	L	M
701	80-35-F	7378	.9984	.9989	8962	5.11	8.90	8.99	9.40	259.8	57.57
702	80-45-F	9176	.9968	.9077	10883	6.21	8.94	9.02	9.58	315.5	57.38
705	160-35-F	11282	.9949	.9964	13658	7.79	8.90	8.98	9.48	395.8	57.55
706	160-40-F	12788	.9978	.9984	15526	8.86	8.37	8.48	8.99	450.1	54.20
707	160-45-F	15193	.9986	.9990	18489	10.55	6.84	6.90	7.36	535.9	44.20
708	160-45-F	15014	.9956	.9969	18276	10.42	6.29	6.89	7.34	529.7	44.37
709	240-30-F	11137	.9969	.9978	13592	7.75	8.48	8.54	9.22	393.9	55.34
710	240-35-F	12710	.9979	.9985	15510	8.85	7.08	7.16	7.66	449.6	45.77
711	240-40-F	15804	.9977	.9984	19299	11.01	5.42	5.48	6.08	559.4	36.66
712	280-30-F	15244	.9936	.9955	18529	10.57	7.24	7.34	7.81	537.1	47.21



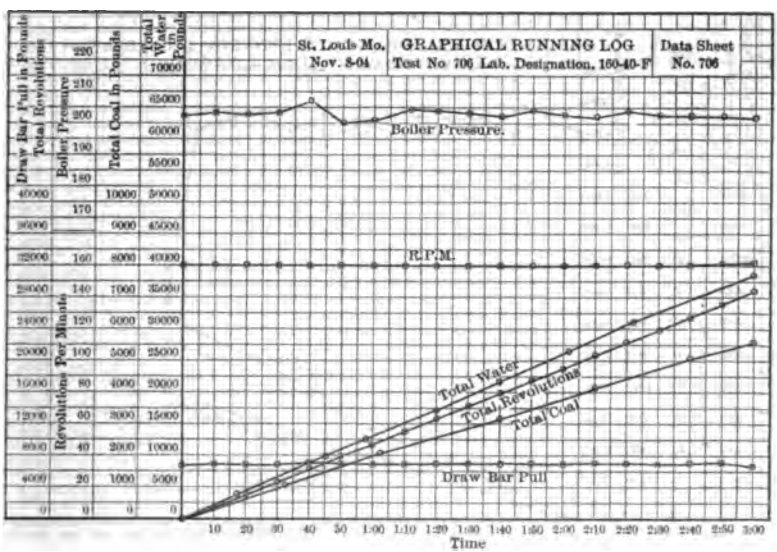
Test No. 701.



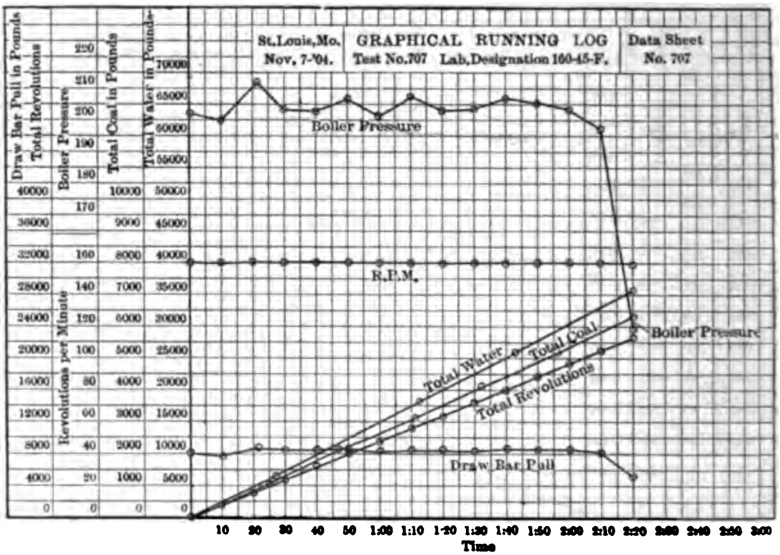
Test No. 702.



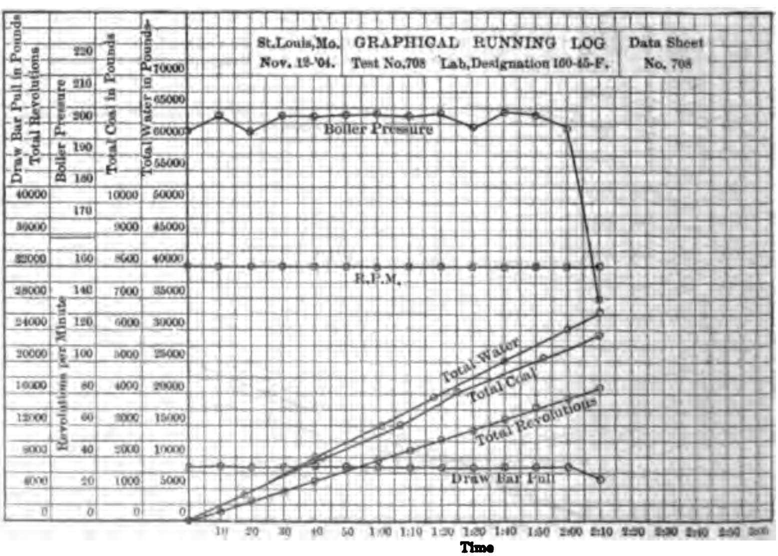
Test No. 705.



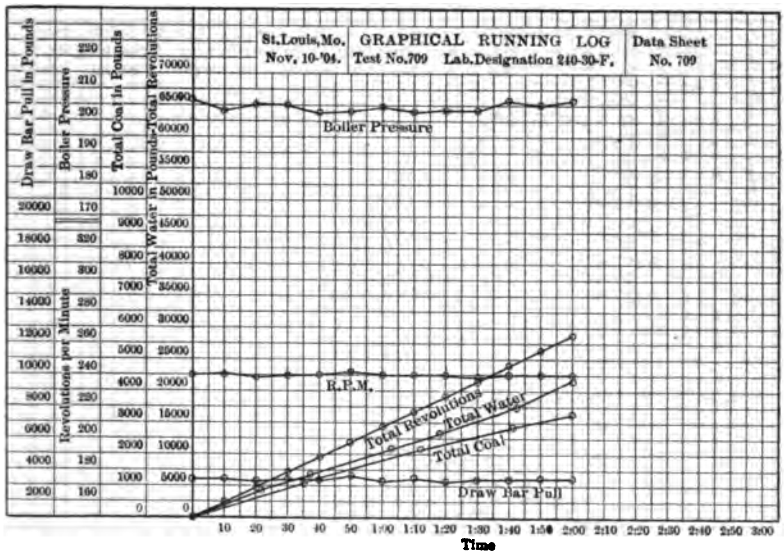
Test No. 706.



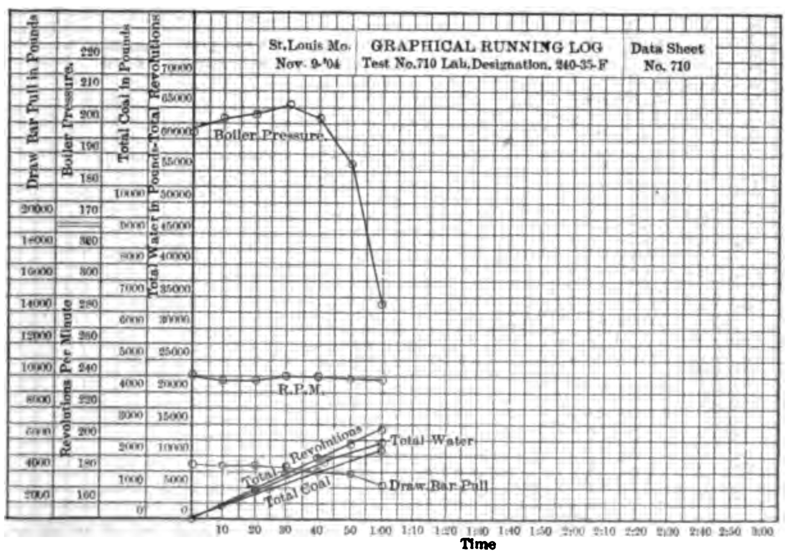
Test No. 707.



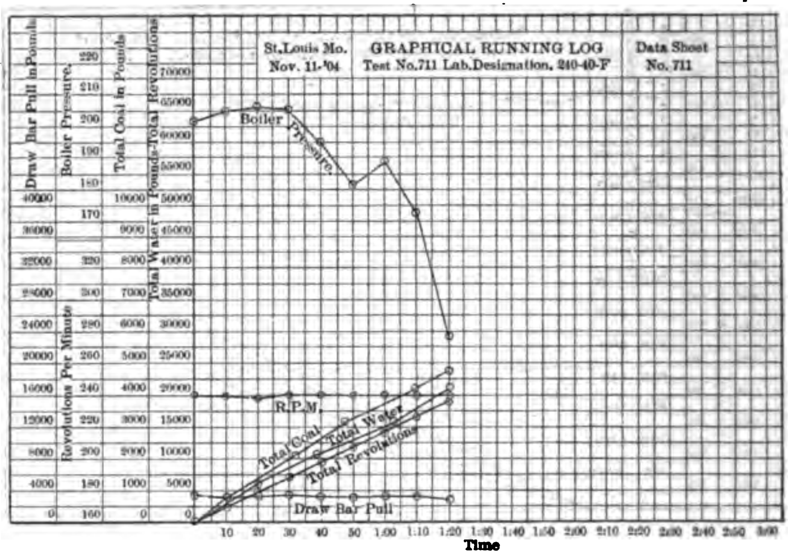
Test No. 708.



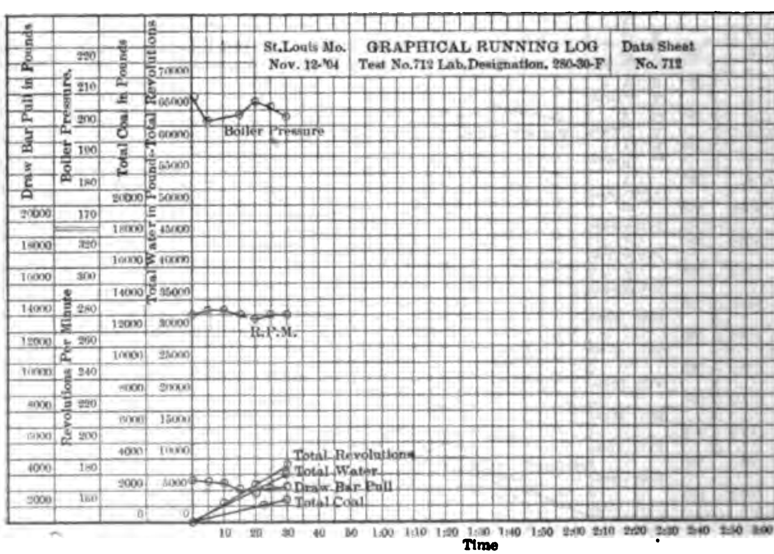
Test No. 709.



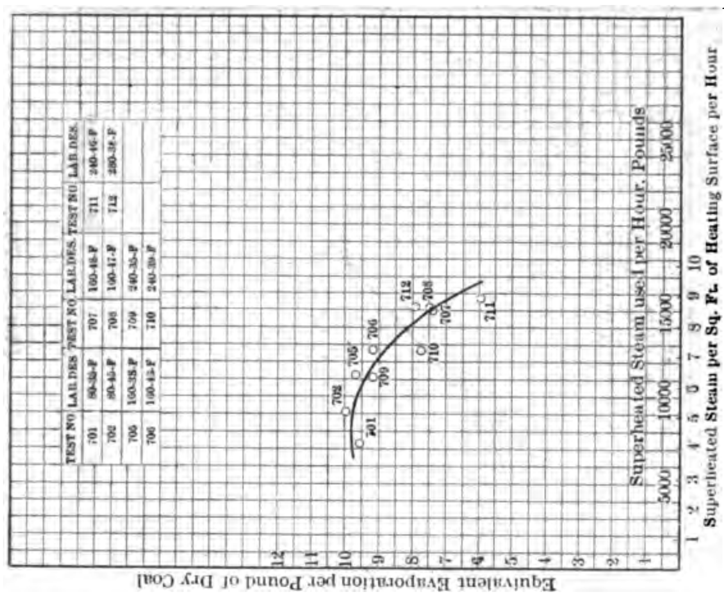
Test No. 710.



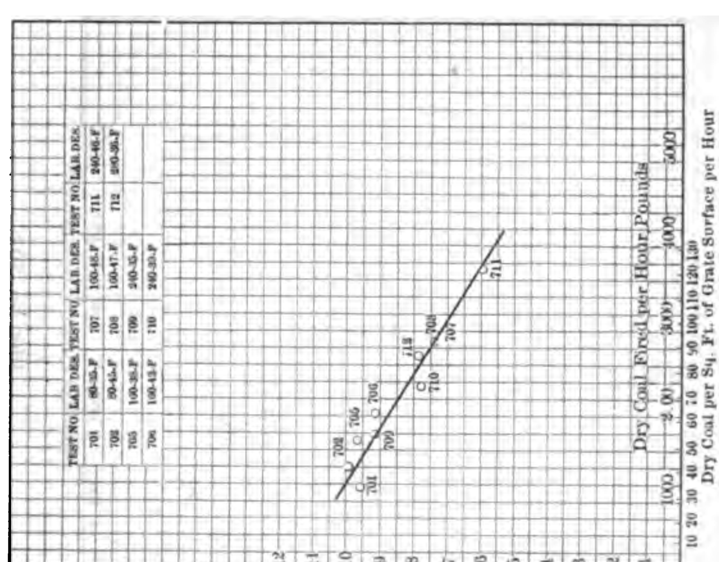
Test No. 711.



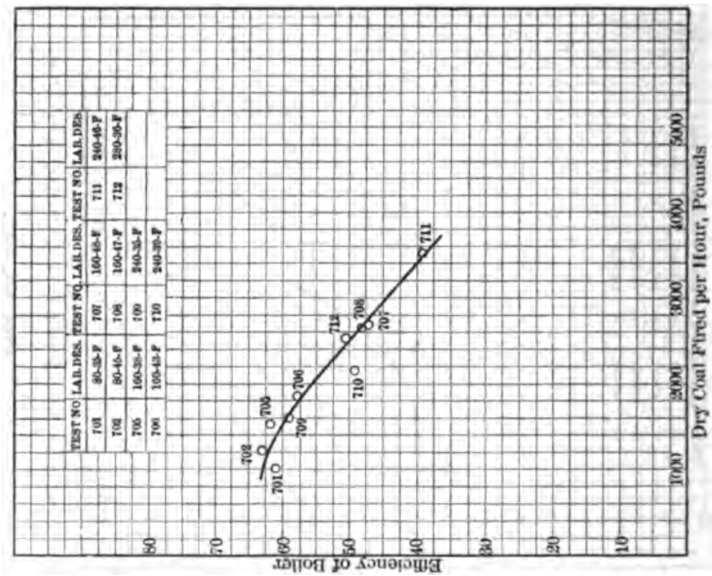
Test No. 712.



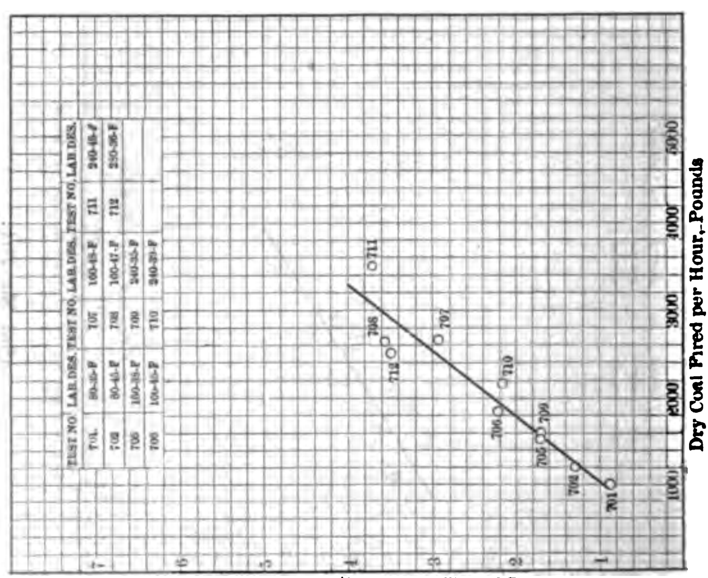
Plot No. 702.



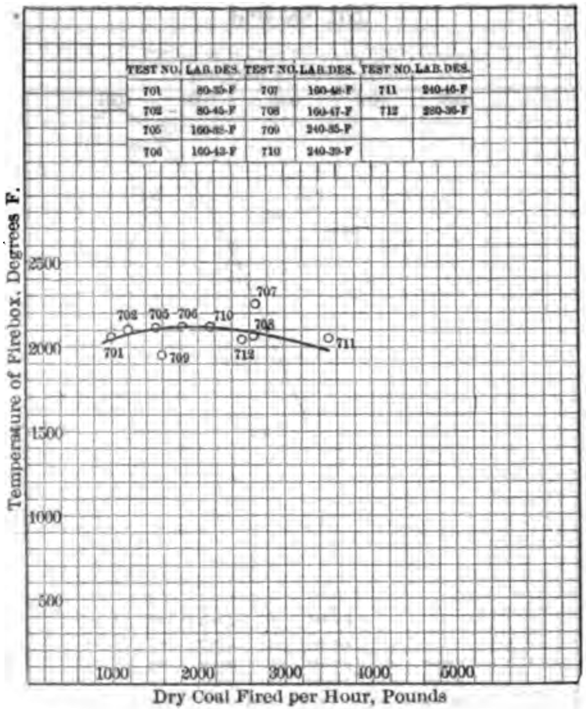
Plot No. 701.



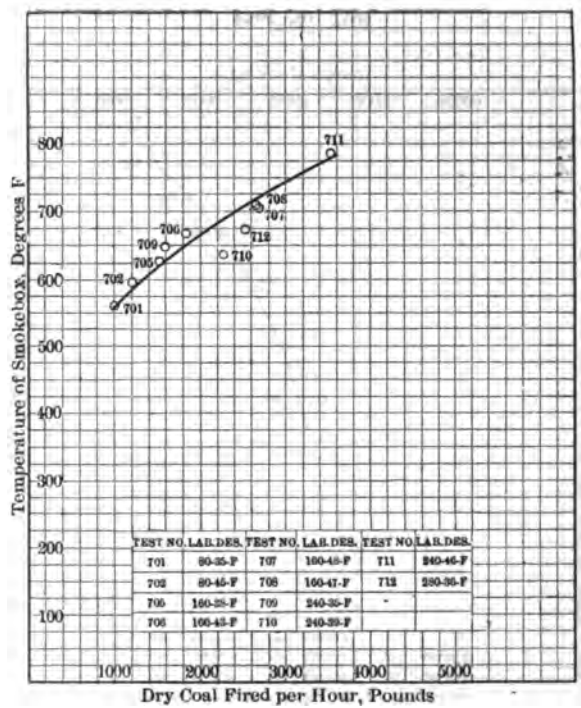
Plot No. 704.



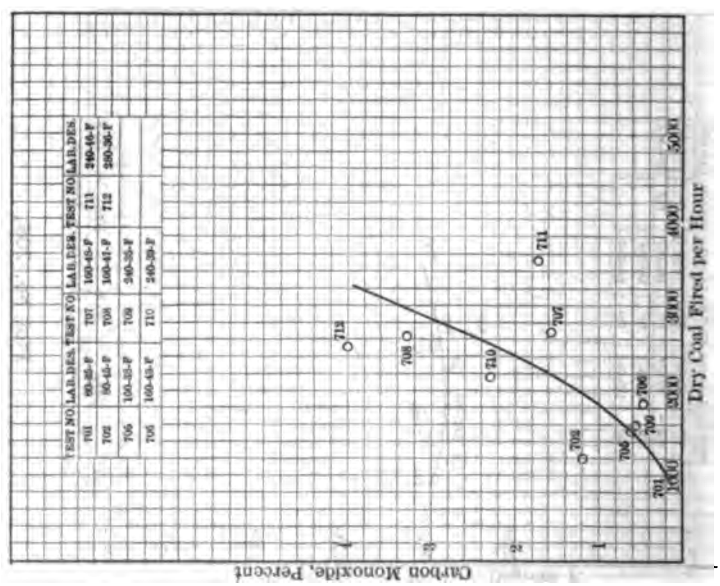
Plot No. 703.



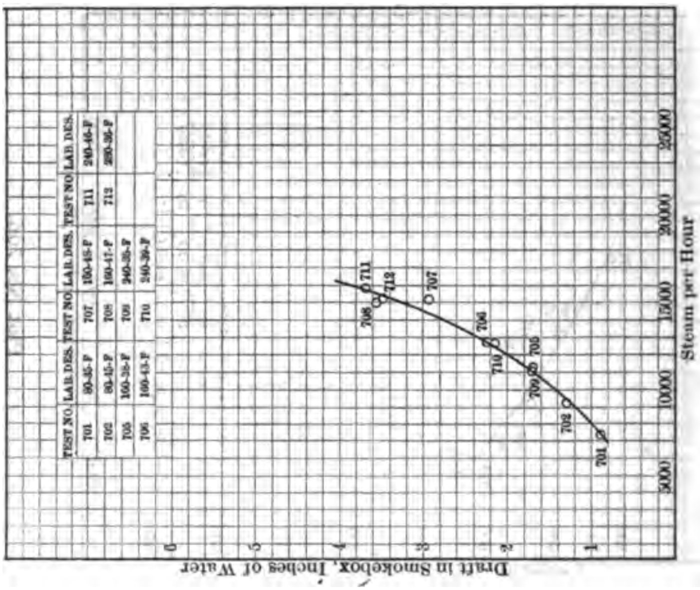
Plot No. 705.



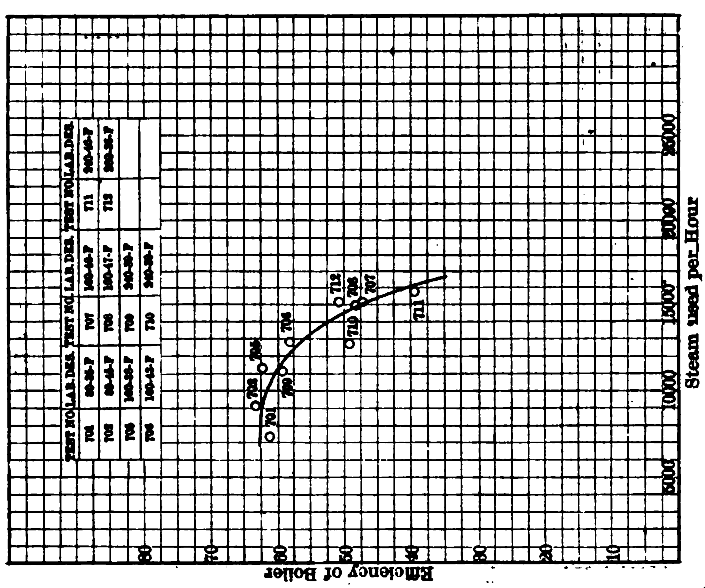
Plot No. 706.



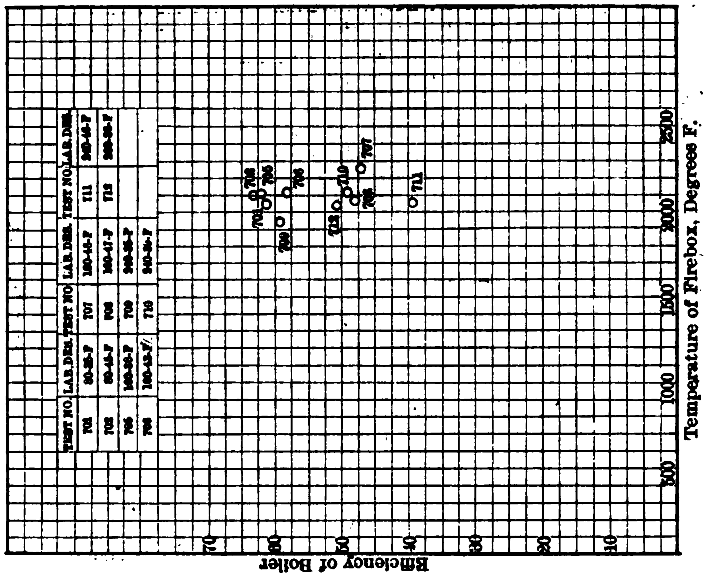
Plot No. 707.



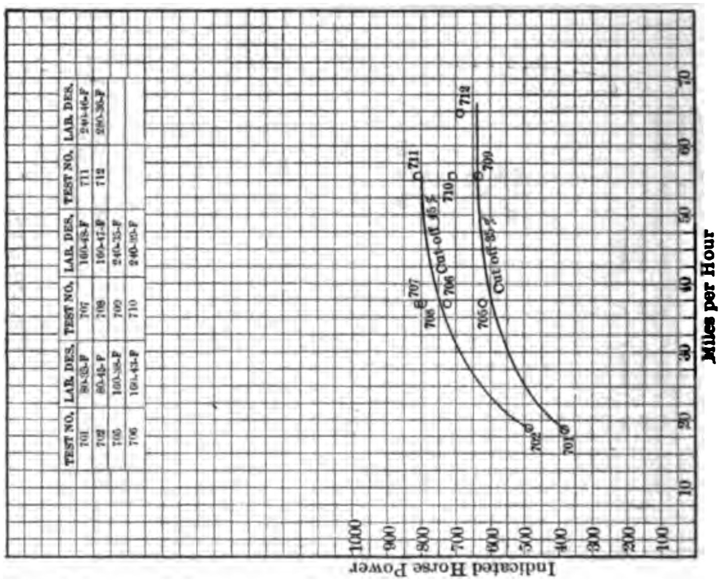
Plot No. 708.



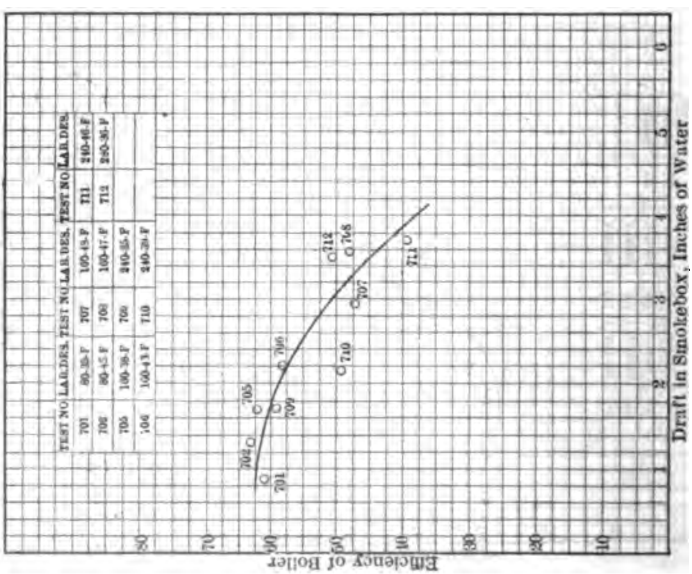
Plot No. 709.



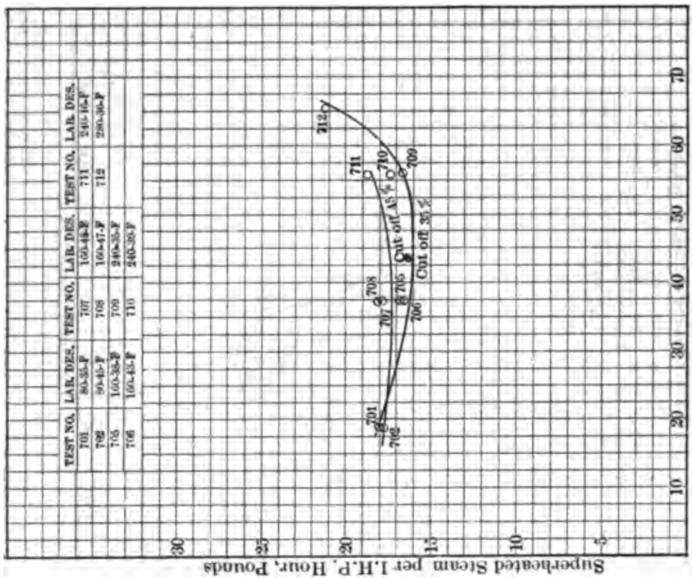
Plot No. 710.



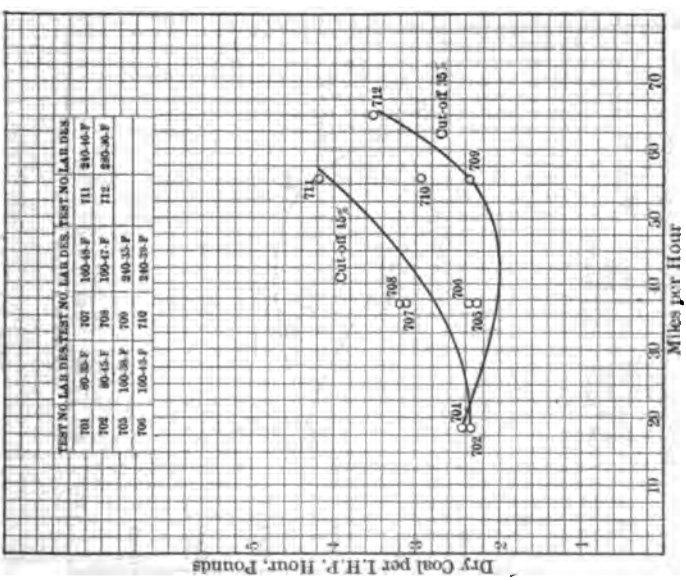
Plot No. 720.



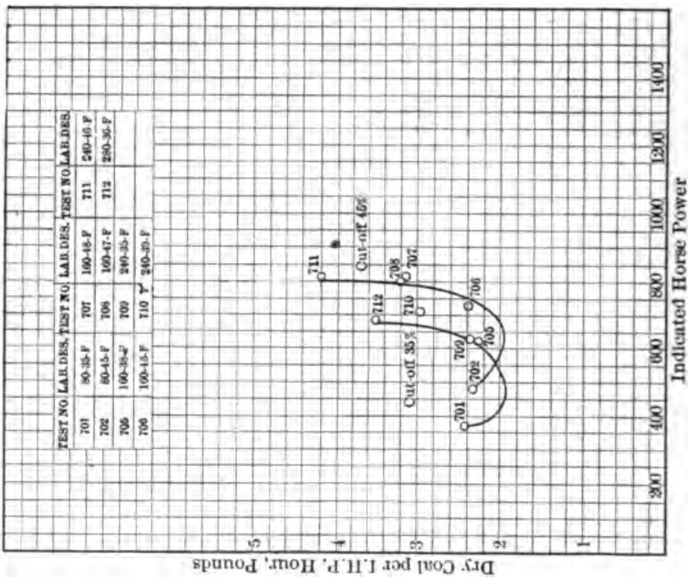
Plot No. 711.



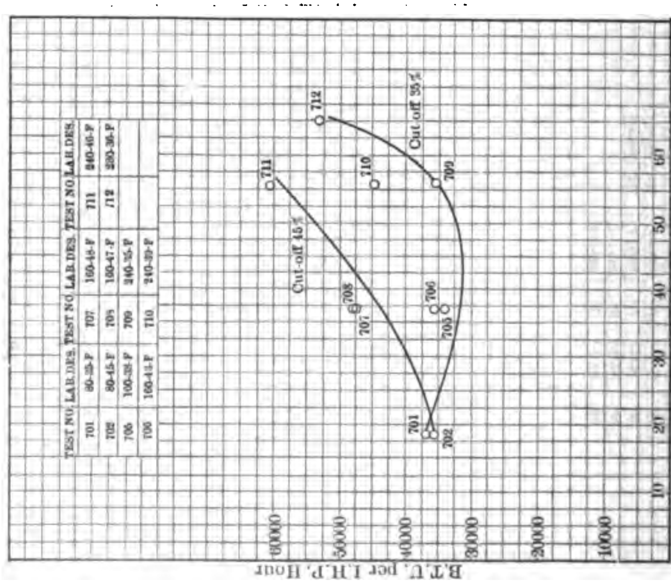
Plot No. 722.



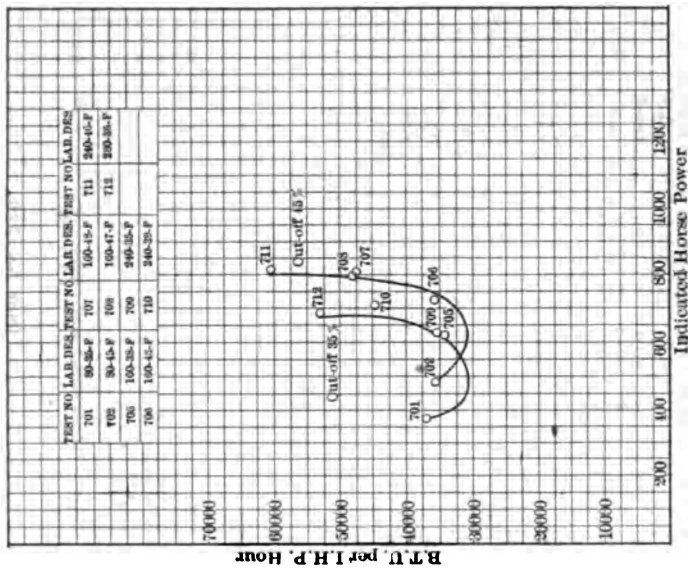
Plot No. 721.



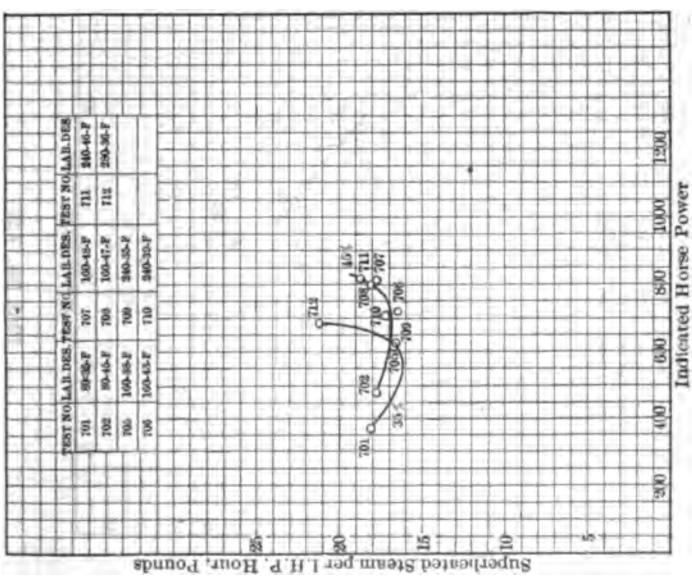
Plot No. 724.



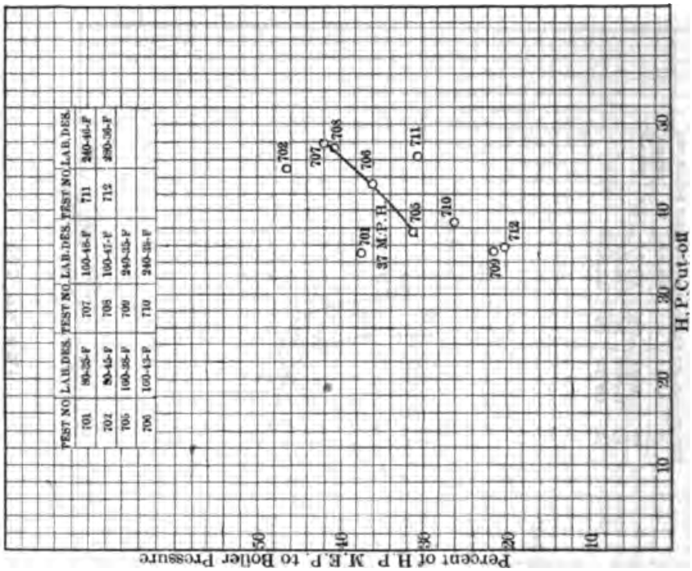
Plot No. 723.



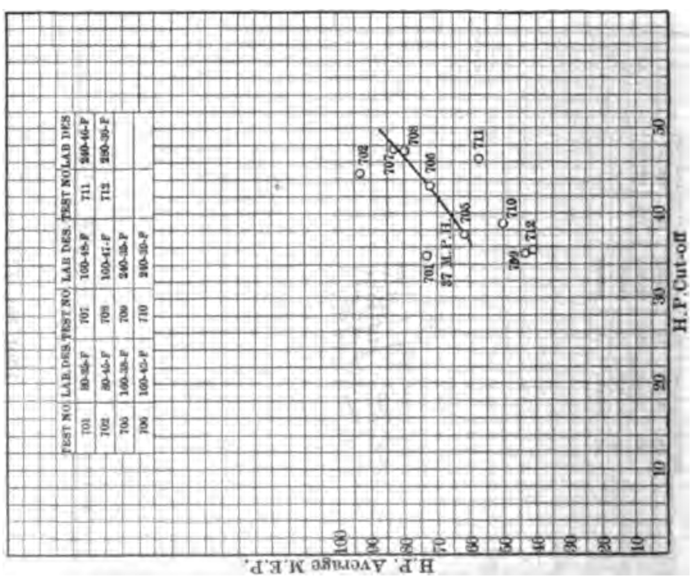
Plot No. 726.



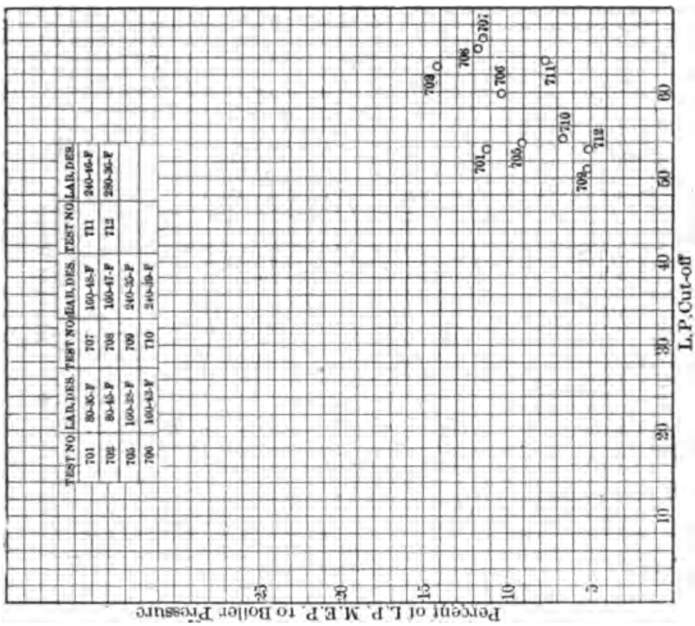
Plot No. 725.



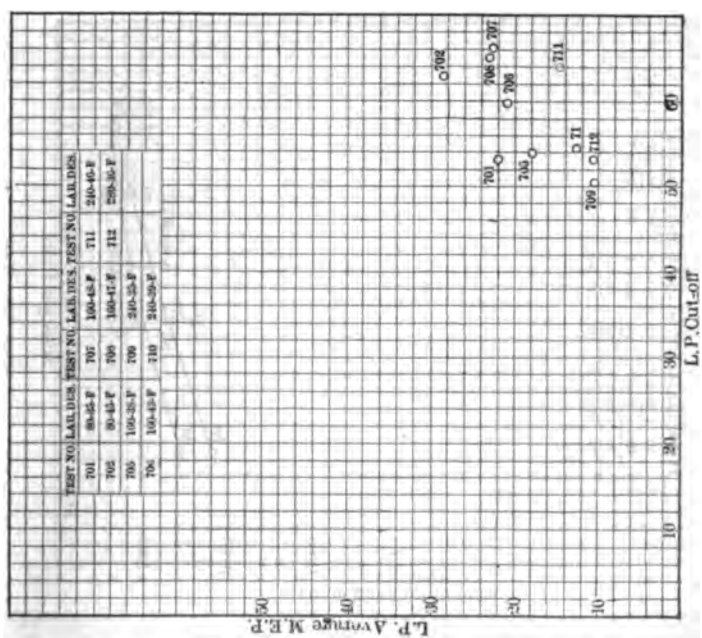
Plot No. 728.



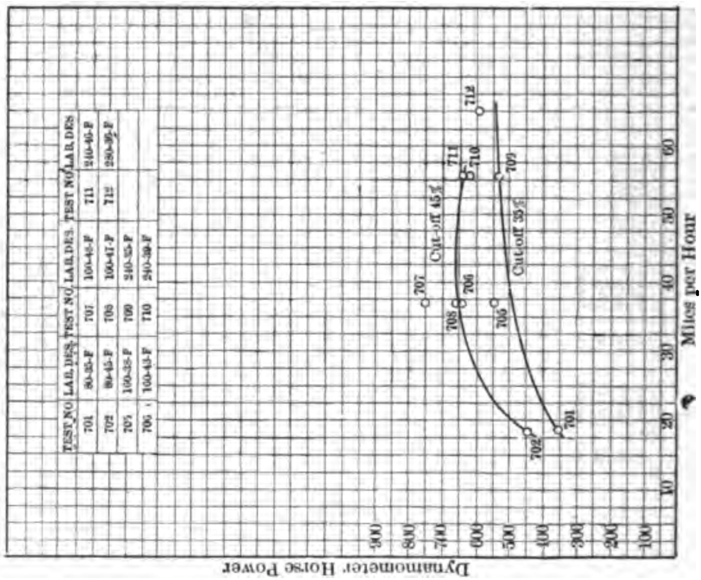
Plot No. 727.



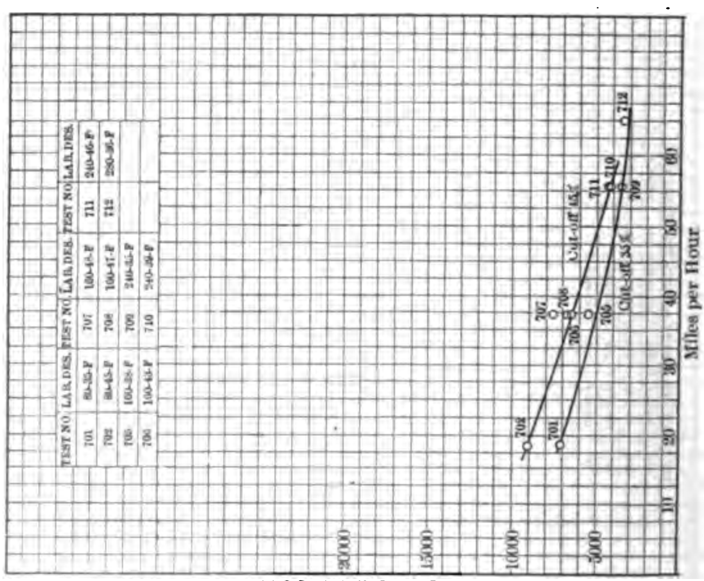
Plot No. 730.



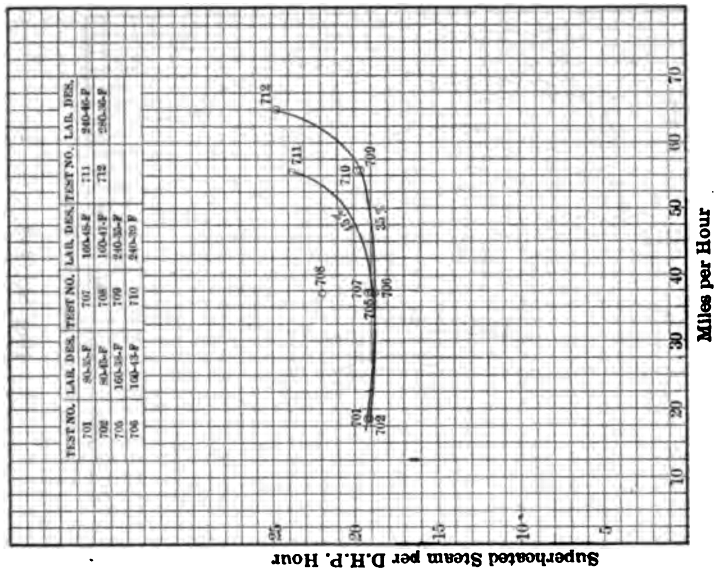
Plot No. 729.



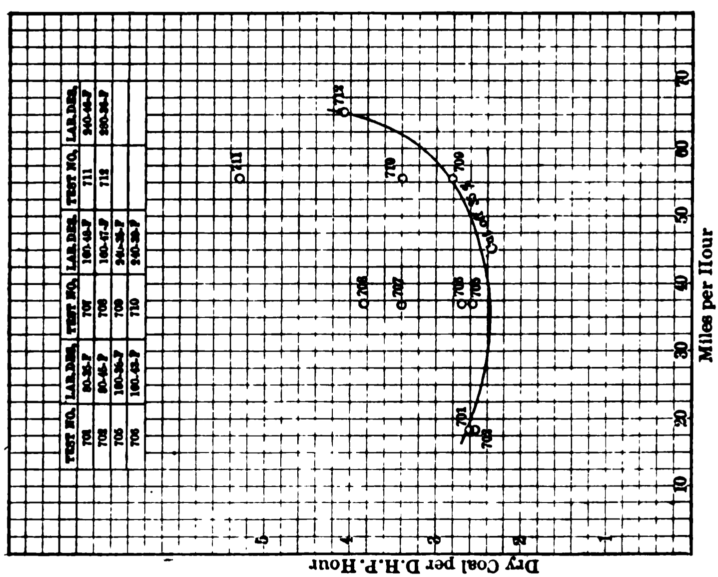
Plot No. 741.



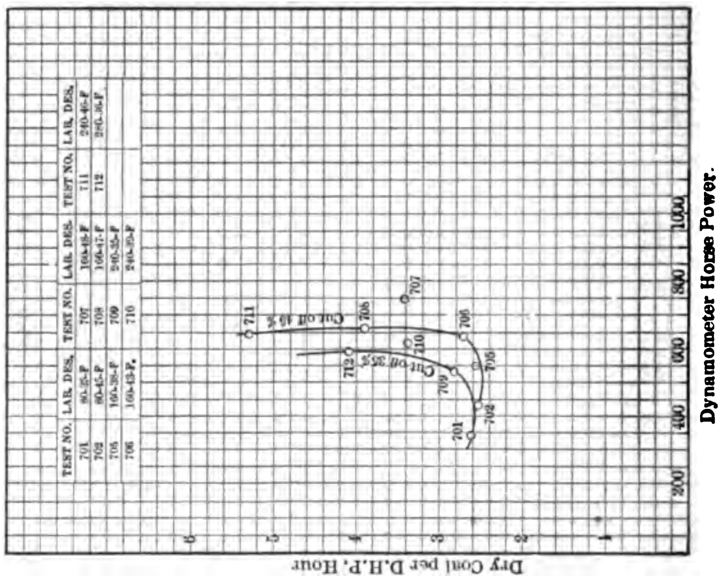
Plot No. 740.



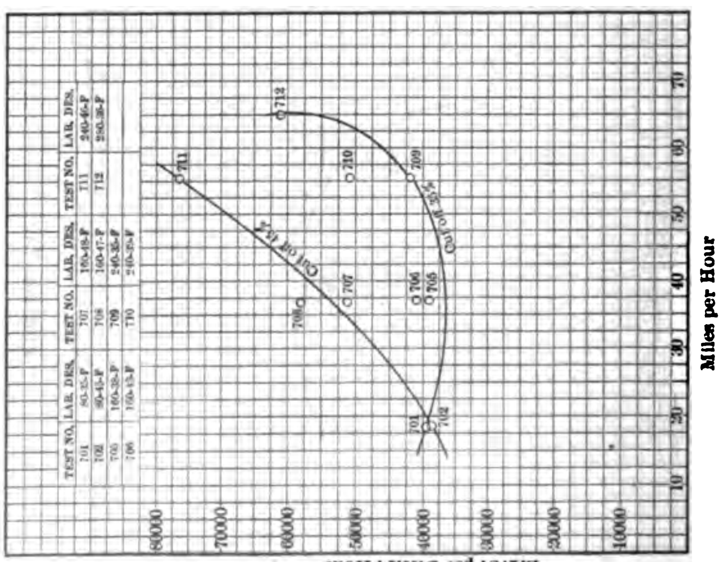
Plot No. 743.



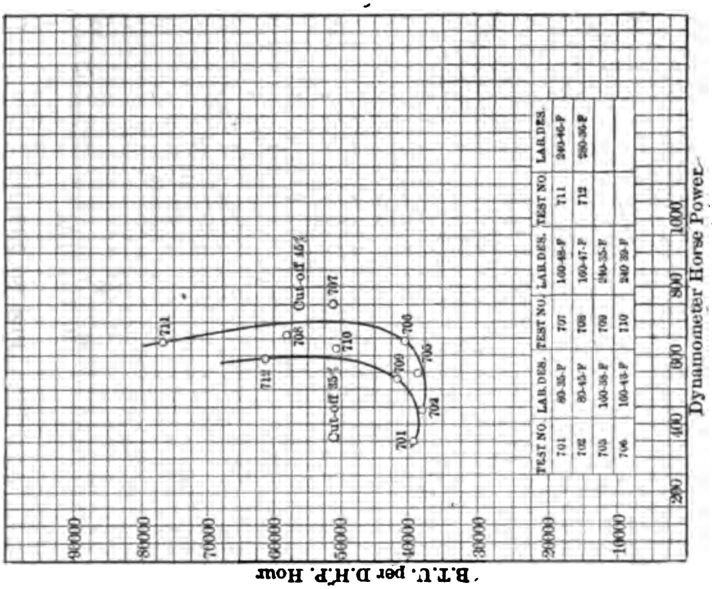
Plot No. 742.



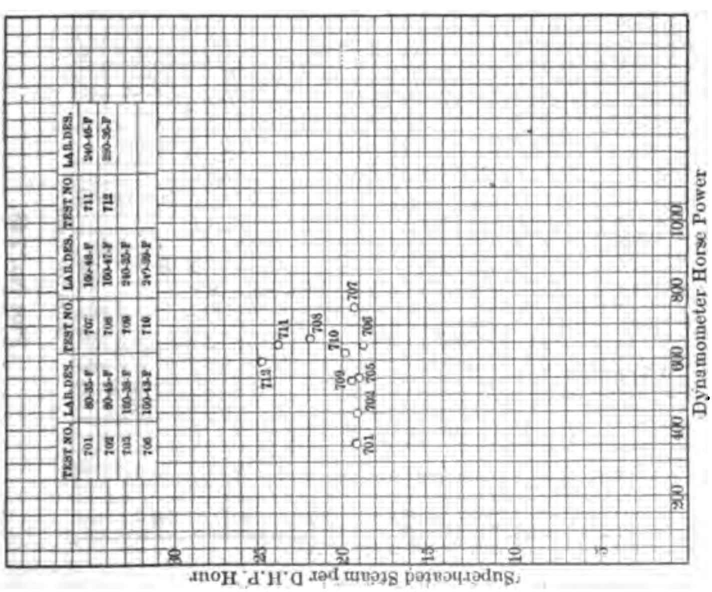
Plot No. 745.



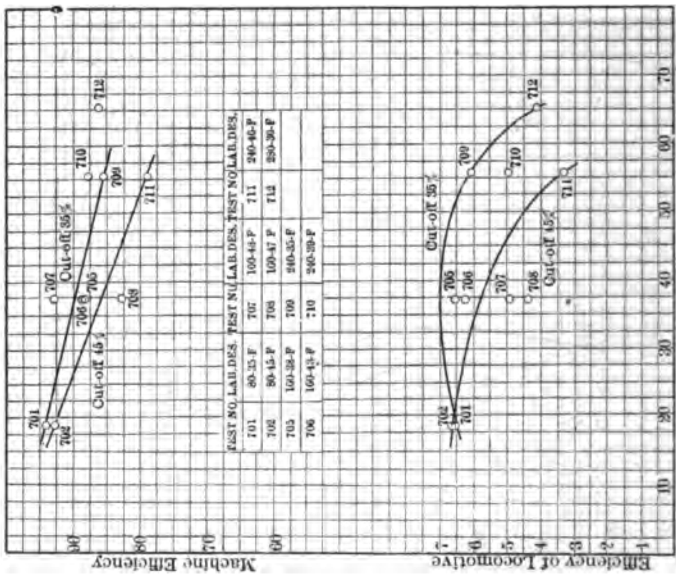
Plot No. 744.



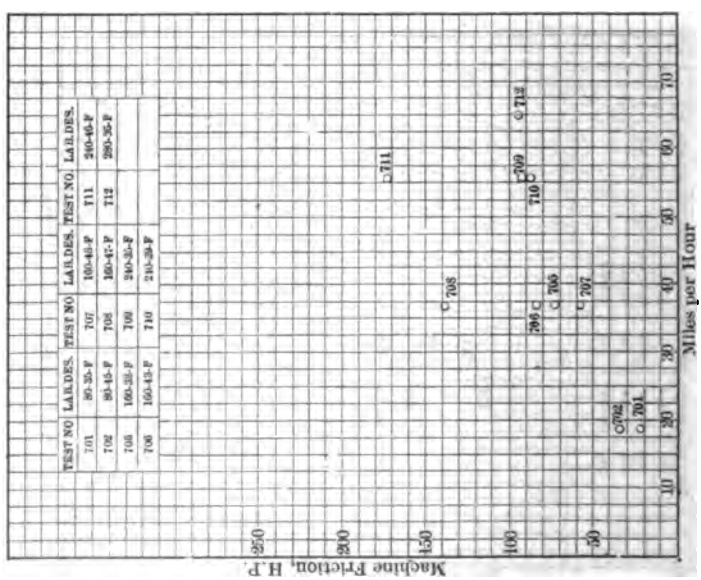
Plot No. 747.



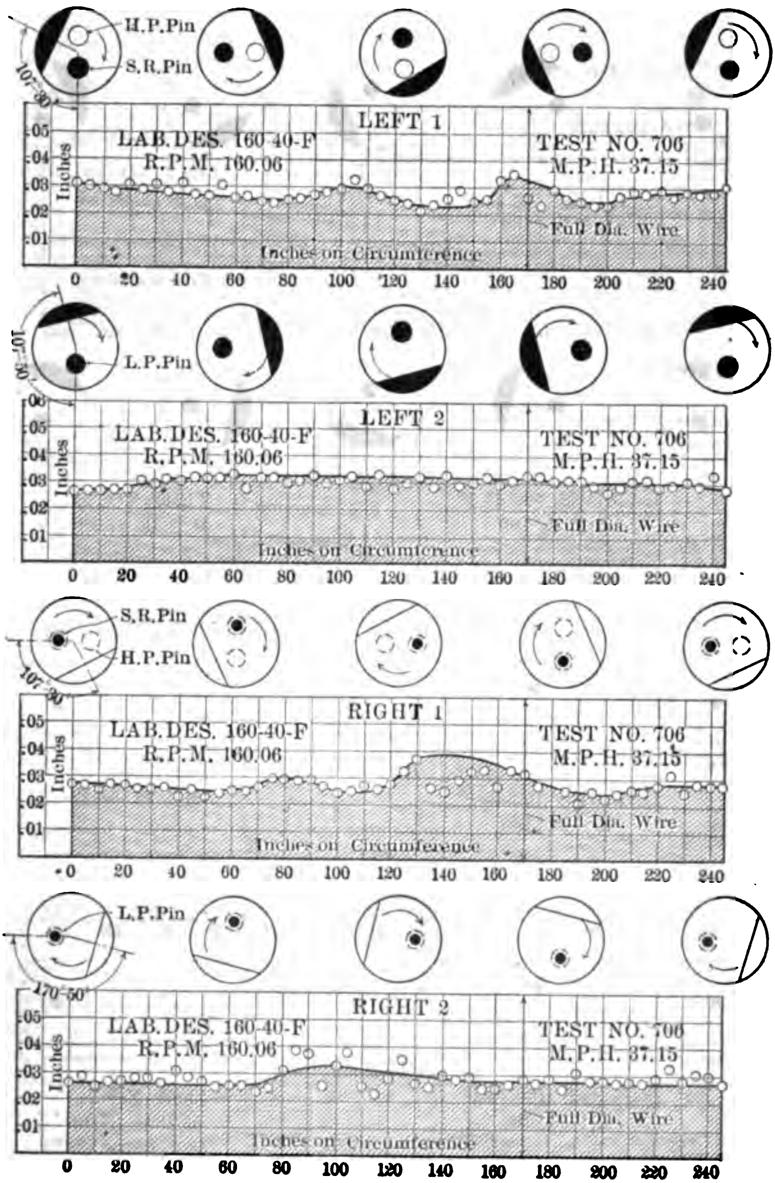
Plot No. 746.



Plot No. 749.

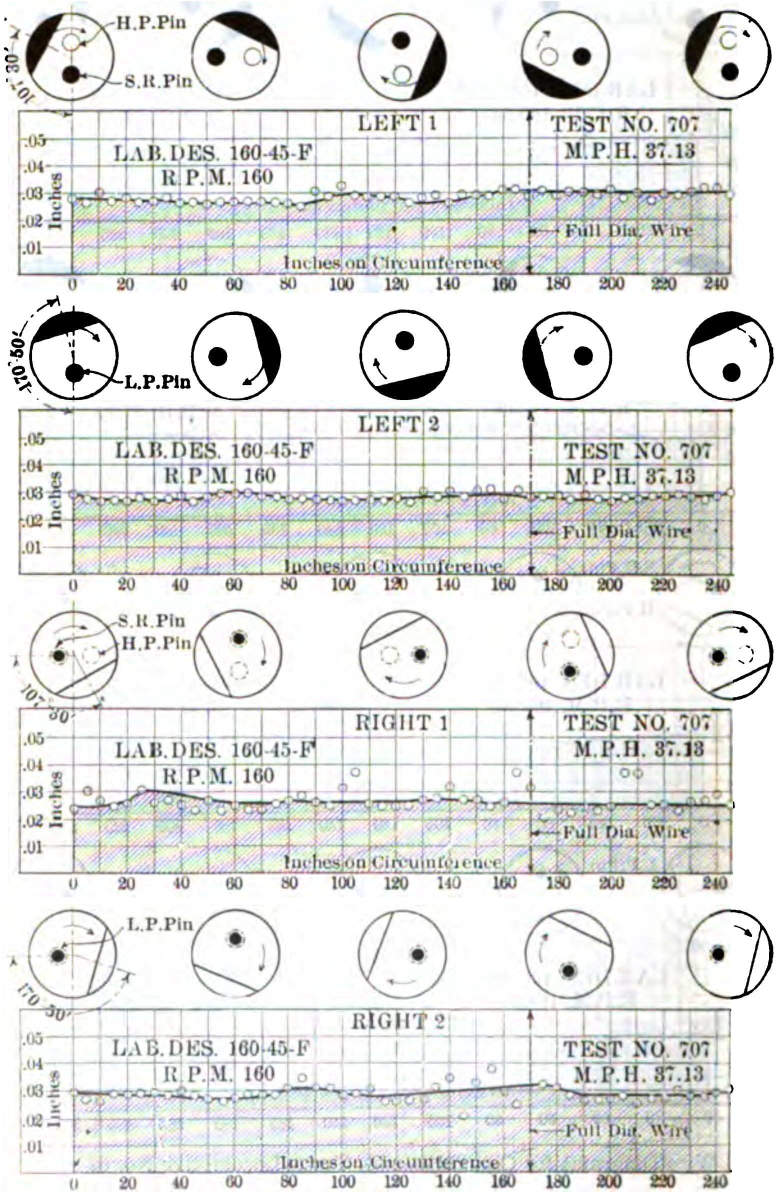


Plot No. 748.

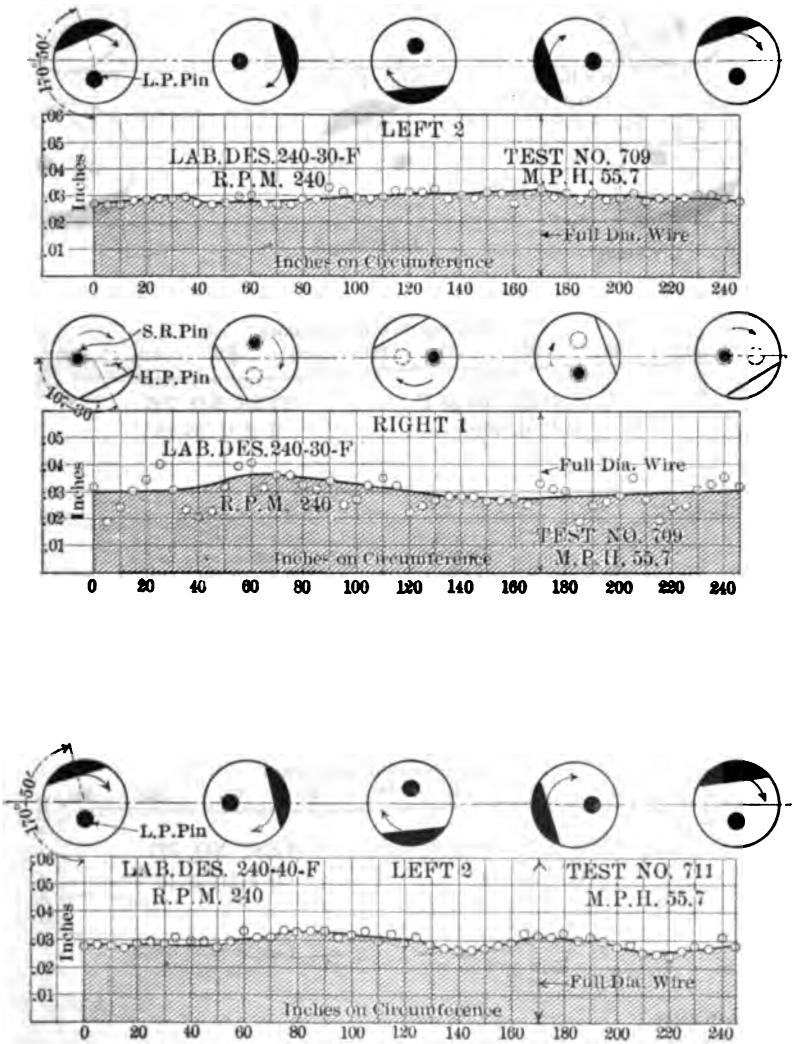


Wire Diagrams for Counterbalance Tests, Locomotive No. 628.

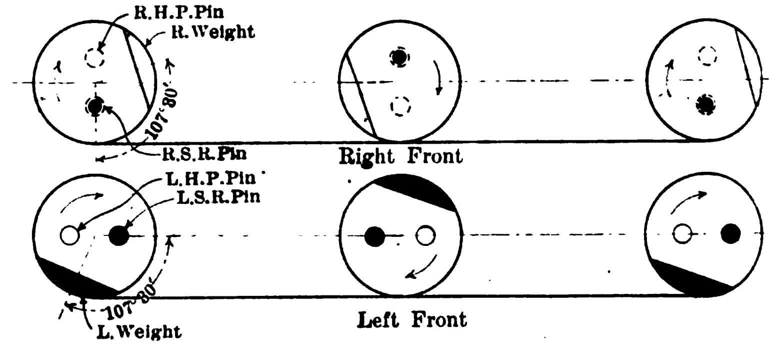
For explanation see page 451.

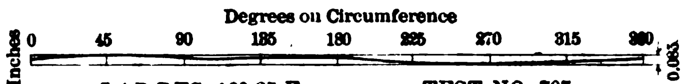


Wire Diagrams for Counterbalance Tests, Locomotive No. 628.

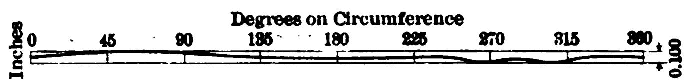


Wire Diagrams for Counterbalance Tests, Locomotive No. 628.

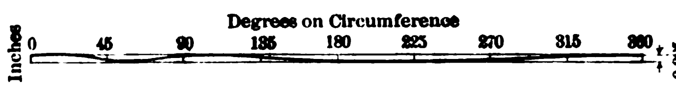




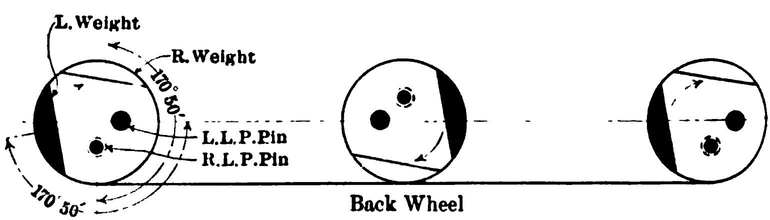
LAB. DES. 160-35-F TEST NO. 705
R.P.M. 160 M.P.H. 37.13



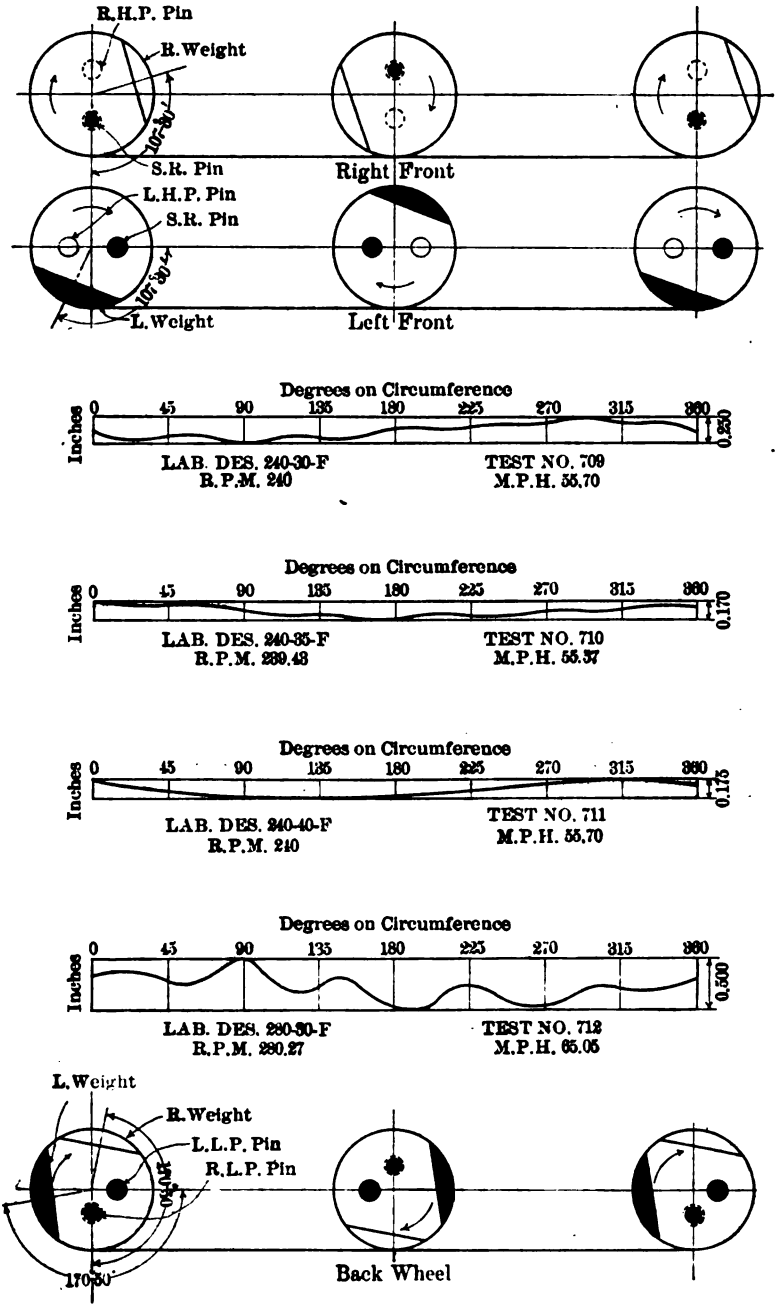
LAB. DES. 160-40-F TEST NO. 706
R.P.M. 160.06 M.P.H. 37.15



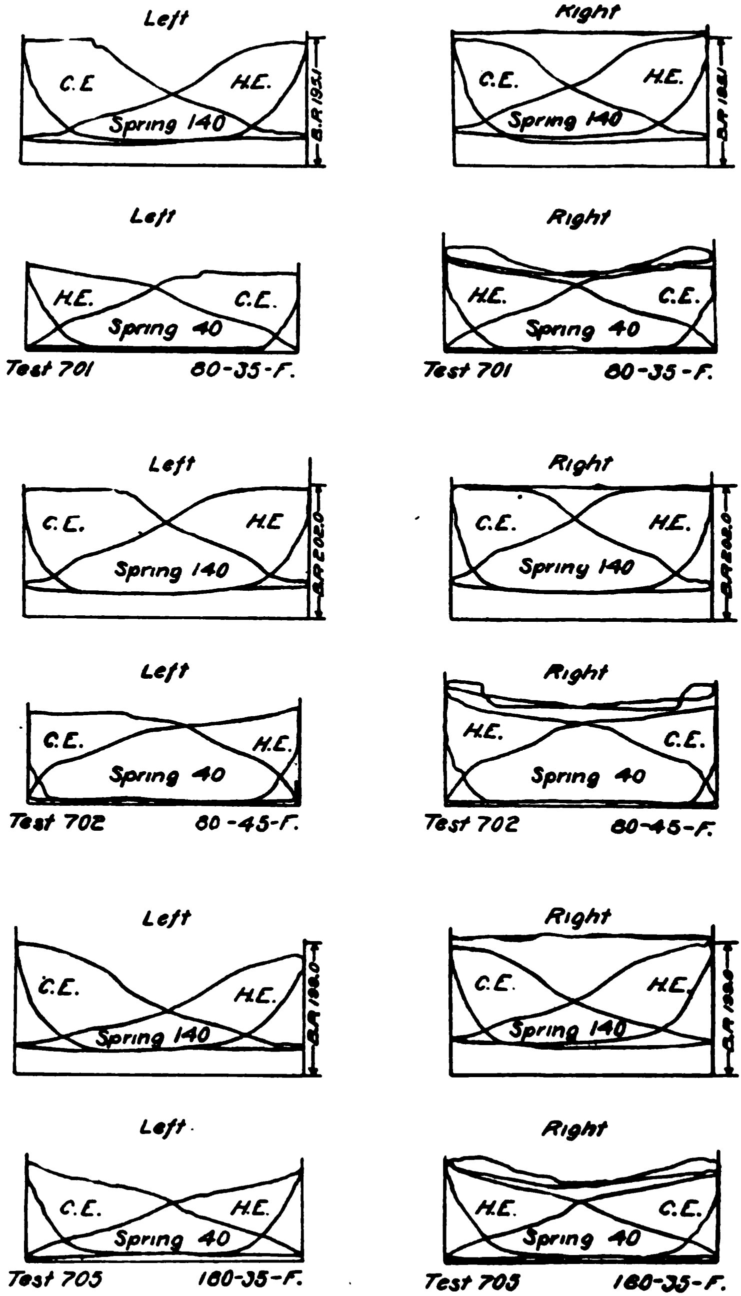
LAB. DES. 160-45-F TEST NO. 707
R.P.M. 160 M.P.H. 37.13



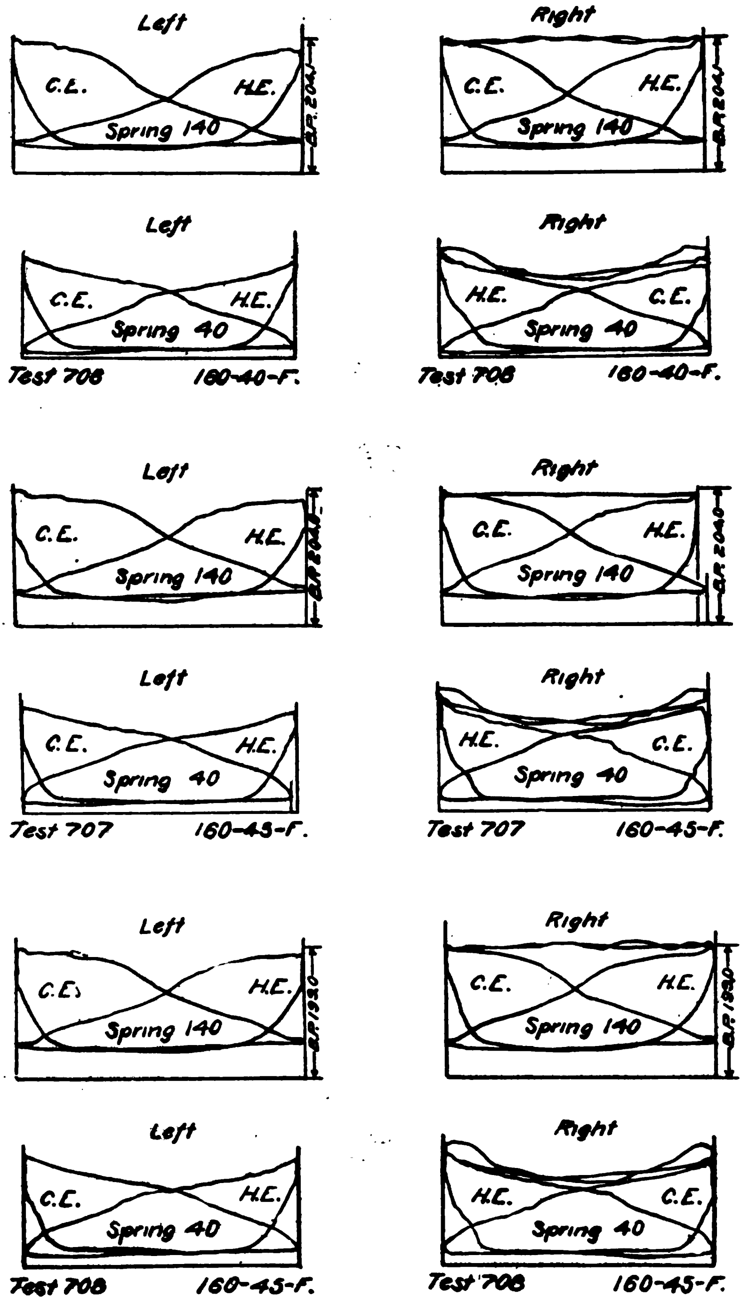
Nosing Diagrams, Locomotive No. 628.



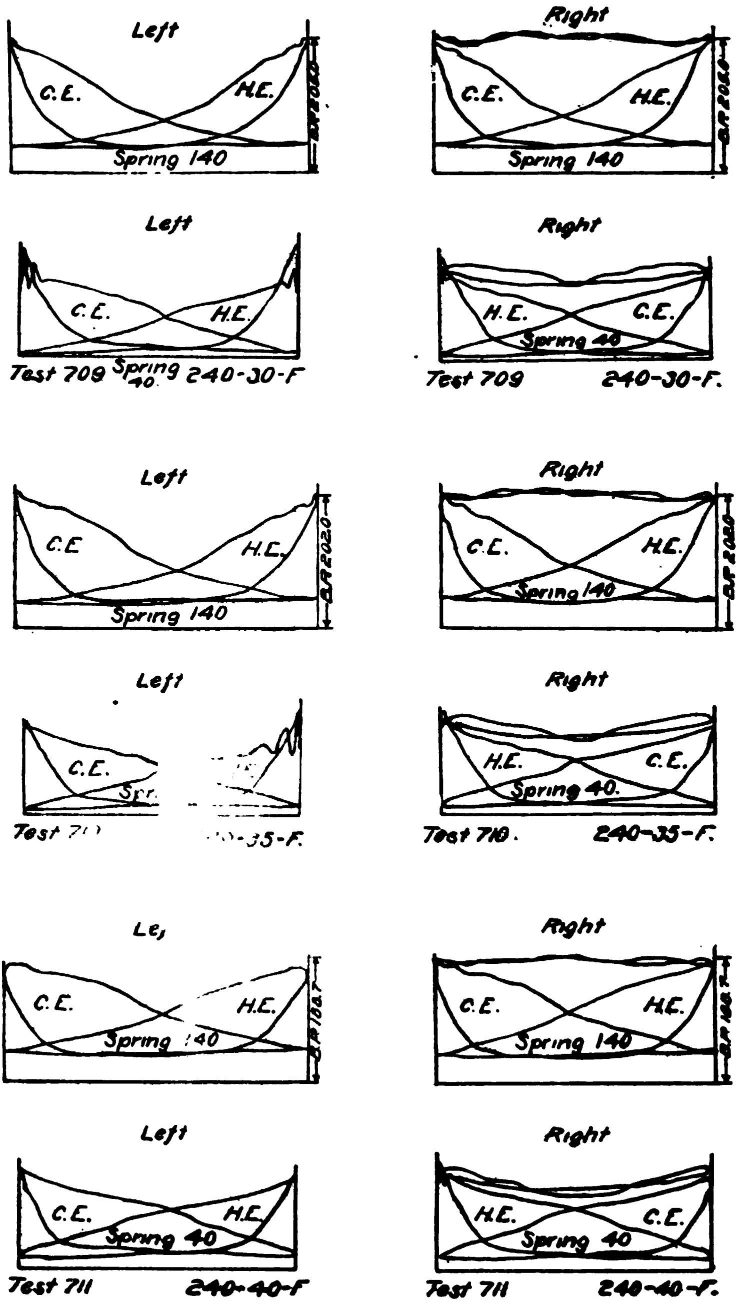
Nosing Diagrams, Locomotive No. 628.



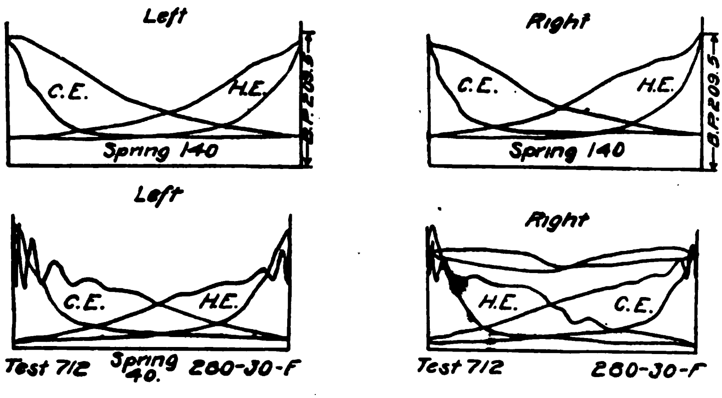
Typical Indicator Diagrams, Locomotive No. 628.



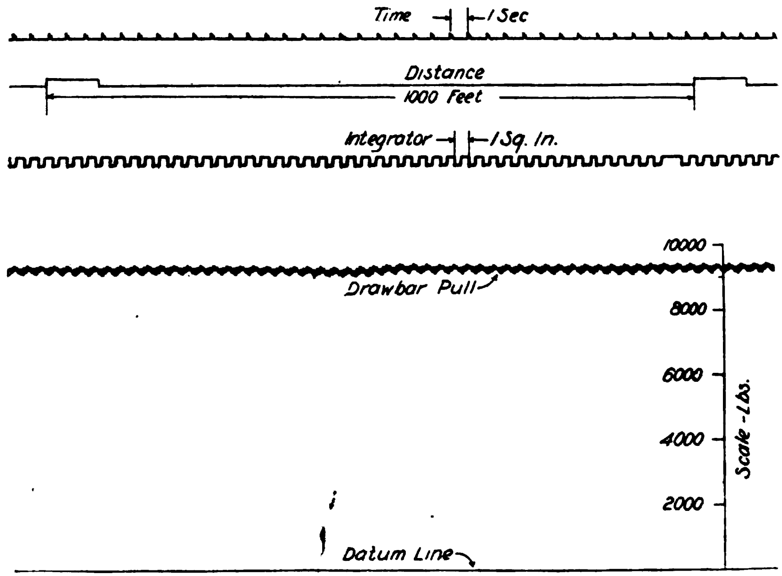
Typical Indicator Diagrams, Locomotive No. 628.



Typical Indicator Diagrams, Locomotive No. 628.



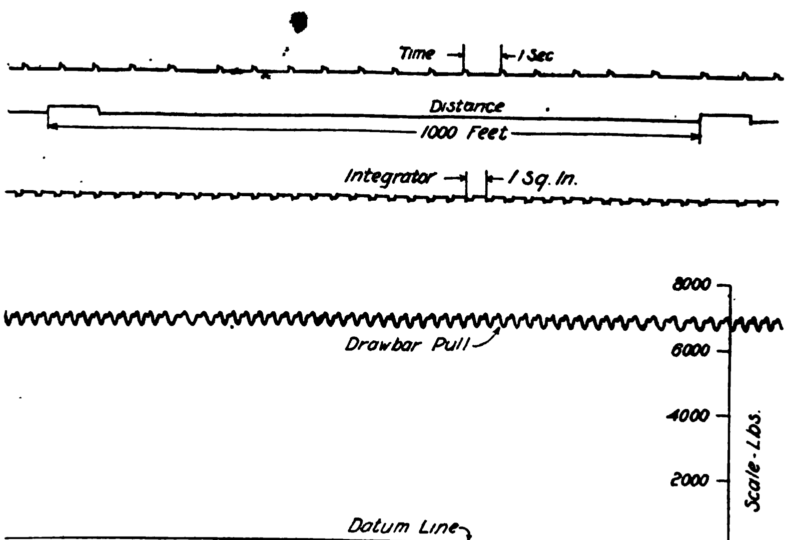
Typical Indicator Diagrams, Locomotive No. 628.



Test 702 Lab. Desig 80-45-F

Dashpots in Safety Bars Not Throttled

Speed, 18.57 Miles per Hour.

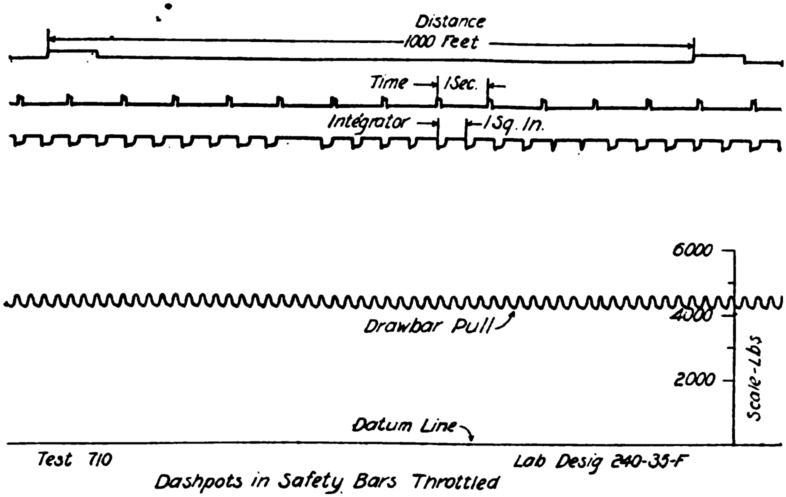


Test 706 Lab. Desig. 160-40-F

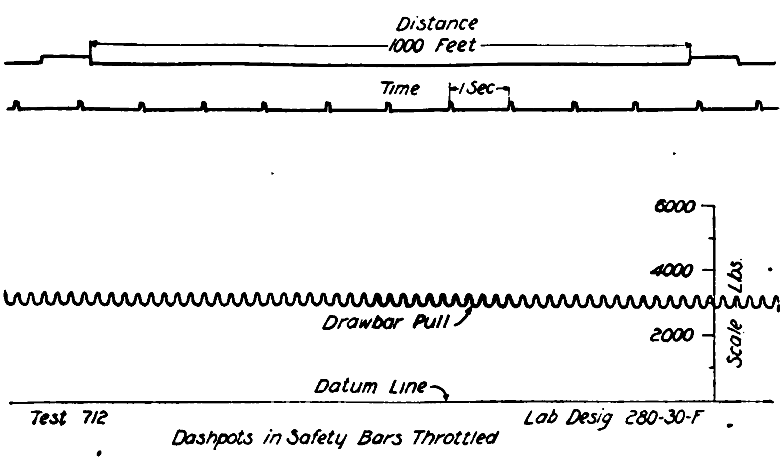
Dashpots in Safety Bars Not Throttled

Speed, 37.15 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 628.



Speed, 55.57 Miles per Hour.



Speed, 65.05 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 628.

Fig. 712.

Elevation Showing Position of Instruments

CHAPTER XX.

TESTS OF ATLANTIC TYPE LOCOMOTIVE, NEW YORK CENTRAL AND HUDSON RIVER RAILROAD.

The eighth locomotive tested was No. 3000, owned by the New York Central & Hudson River Railroad Company, and built by the American Locomotive Company at its Schenectady Works. It was of the 4-4-2 type and known as the I1 class according to the railroad company's classification. It was a four-cylinder balanced compound designed by Mr. F. J. Cole.

This locomotive had two high pressure cylinders between the frames set a little forward of the smoke-box. These high pressure cylinders were connected to the forward axle, the cranks of which were set quartering. The low pressure cylinders were outside the frames and connected to the second driving axle. Each outside crank pin was set 180 degrees with its adjacent inside crank. This arrangement made necessary the use of shorter connecting rods on the inside than on the outside.

The cut-off in the high and low pressure cylinders could not be varied independently as the valve for each set of high and low pressure cylinders was actuated by a single valve gear.

The steam for the high pressure cylinders passed through an opening in the saddle to a short pipe entering the top of the steam chest.

When working simple, a starting valve operated from the cab, admitted live steam, at a reduced pressure, to the low pressure cylinders.

The "Perfection" fuel economizer, consisting of special fire doors and means for admitting air above the fire was used on this locomotive.

The locomotive was placed on the plant November 13 and removed November 24. During these twelve days, eleven tests were run. The last test run was at a speed of 320 revolutions or 75 miles an hour and lasted for one hour. It was not possible to run any of the other locomotives at that speed for that length of time.

The critical speed of this locomotive was more than 310 revolutions and probably about 320. This was a higher critical speed by over 100 revolutions, than that attained by any other locomotive on the plant.

It ran very steadily and showed excellent counterbalancing in every way.

The principal dimensions and the details of the locomotive are given in Appendix 800. The principal nominal dimensions are shown in the following table:

Total weight, pounds	200,000
Weight on drivers, pounds	110,000
Cylinders (compound), inches	15½ & 26 x 26
Diameter of drivers, inches	79
Fire-box heating surface, square feet	151.69
Heating surface in tubes (water side) .. square feet	3255.27
Total heating surface (based on water side of tubes) sq. ft.	3406.96
*Total heating surface (based on fire-side of tubes), sq. ft.	3000.05
Grate area, square feet	49.90
Boiler pressure, pounds	220
Valves	Piston
Link motion	Stephenson
Fire-box, type	Wide
Number of tubes	390
Outside diameter of tubes, inches	2
Length of tubes, inches	191.29

The maximum tractive effort was 27,899 pounds working simple and 20,590 pounds working compound, which was calculated on the assumption that 80 per cent. of the boiler pressure (220 pounds) was available as mean effective pressure at starting. On this basis the ratio of weight on drivers to maximum tractive effort was 3.94:1 working simple and 5.34:1 working compound.

* Used in Calculations

TESTS.

The tests which have been run, together with the laboratory designations and dates of running, are as follows:

Test No.	Laboratory Designation.	Date.
801	80-35-F	November 15th
802	80-45-F	" 16th
805	160-35-F	" 17th
806	160-45-F	" 21st
807	160-55-F	" 23rd
809	240-35-F	" 21st
811	240-50-F	" 22nd
812	240-55-F	" 24th
813	280-35-F	" 22nd
814	280-40-F	" 24th
815	320-40-F	" 24th

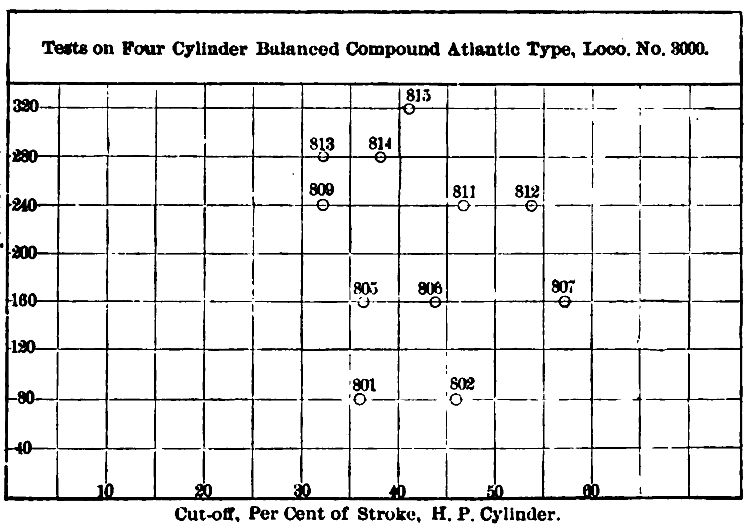


Fig. 801.

BOILER PERFORMANCE.

GENERAL CONDITIONS—TABLE 801.

The tests are arranged in order, according to the rate of equivalent evaporation.

The lowest average boiler pressure was 209.4 pounds, while

TABLE No. 801—GENERAL BOILER CONDITIONS.

Identification of Test		Duration of Test, Minutes	Average Pressure Lbs. Per Sq. Inch		Average Temperature, Degrees Fahr.		Total Coal Fired Per Sq. Ft. of Grate Lbs.
Test Number	Laboratory Designation		Boiler Pressure	Atmospheric Pressure	Of Laboratory	Of Feed Water	
		Cal.	217	221	208	211	Cal.
801	80–35–F	180	209.4	14.549	51.7	48.8	78.18
802	80–45–F	180	210.8	14.601	54.8	52.2	106.15
805	160–35–F	180	222.2	14.569	50.1	50.0	142.99
809	240–35–F	120	218.7	14.488	52.9	50.0	122.32
806	160–45–F	180	220.4	14.536	41.8	49.8	188.95
813	280–35–F	90	220.0	14.509	50.9	49.0	105.49
814	280–40–F	60	220.2	14.508	49.8	49.0	78.74
815	320–40–F	60	222.3	14.514	51.5	48.5	99.72
807	160–55–F	180	221.4	14.443	50.4	49.6	296.51
811	240–50–F	120	219.6	14.510	42.9	49.0	234.65
812	240–55–F	105.6	212.8	14.524	43.5	49.5	238.75

the highest was 222.3 pounds. The temperature of the feed water was uniform.

The total coal fired per square foot of grate area follows:

In 3 tests ....between 50 and 100 pounds
In 4 tests ....between 100 and 150 pounds
In 1 test ....between 150 and 200 pounds
In 2 tests ....between 200 and 250 pounds
In 1 test .... more than 250 pounds

EVAPORATION—TABLE 802.

The evaporation per hour was between the limits of 12,466 pounds and 41,120 pounds.

There was a tendency for the moisture to increase as the rate of evaporation increased.

This was a very good steaming boiler but when the evapora-

TABLE No. 802—EVAPORATION.

Identification of Test		Duration of Test, Minutes	Water and Steam		Calorimeter Results			Equivalent Evaporation Lbs. Per Hour
Test Number	Laboratory Designation		Total Lbs. Evaporated	Lbs. Evaporated Per Hour	Quality of steam in Dome	Quality of steam in Branch Pipe	Degrees Superheat in Branch Pipe	
		Cal.	264	340	*228	229	230	344
801	80-35-F	180	37400	12466	.9826	.9621	0	15036
802	80-45-F	180	46483	15494	.9835	.9624	0	18703
805	160-35-F	180	59896	19965	.9830	.9642	0	24040
809	240-35-F	120	49573	24787	.9822	.9631	0	29960
806	160-45-F	180	77228	25743	.9827	.9637	0	31142
813	280-35-F	90	40974	27314	.9827	.9631	0	33055
814	280-40-F	60	31561	31561	.9653	.9727	0	37721
815	320-40-F	60	32906	32906	.9530	.9648	0	38973
807	160-55-F	180	101262	33754	.9499	.9570	0	39872
811	240-50-F	120	74092	37046	.9819	.9845	0	44765
812	240-55-F	105.6	72418	41120	.9627	.9653	0	49025

TABLE No. 803—BOILER POWER.

Identification of Test		Duration of Test, Minutes	Equivalent Evaporation, Lbs.		Boiler Horse Power		
Test Number	Laboratory Designation		Per Sq. Ft. of Grate Surface Per Hour	Per Sq. Ft. of Heat'g Surface Per Hour	Total	Per Sq. Ft. of Heating Surface	Per Sq. Ft of Grate Surface
		Cal.	Cal.	345	349	Cal.	Cal.
801	80-35-F	180	301.3	5.01	435.8	.145	8.73
802	80-45-F	180	374.8	6.23	542.2	.181	10.86
805	160-35-F	180	481.7	8.01	696.8	.232	13.96
809	240-35-F	120	600.4	9.99	868.4	.289	17.40
806	160-45-F	180	624.0	10.38	902.6	.301	18.09
813	280-35-F	90	662.4	11.02	958.1	.319	19.20
814	280-40-F	60	755.9	12.57	1093.3	.365	21.91
815	320-40-F	60	781.0	12.99	1129.6	.377	22.64
807	160-55-F	180	799.1	13.29	1155.6	.385	23.16
811	240-50-F	120	897.1	14.92	1297.4	.433	26.00
812	240-55-F	105.6	982.5	16.34	1421.0	.474	28.48

tion was high, as much as five per cent. of moisture was carried by the steam.

BOILER POWER—TABLE 803.

The equivalent pounds of water evaporated per square foot of grate per hour ranged from 301.3 to 982.5.

The equivalent evaporation per square foot of heating surface ranged from 5.01 to 16.34 pounds per hour.

TABLE No. 804—COAL AND RATE OF COMBUSTION.

Identification of Test		Duration of Test, Minutes	Total Dry Coal Fired	Fuel in Pounds			Rate of Combustion	
Test Number	Laboratory Designation			Total Combustible by Analysis	Dry Coal Fired Per Hour	Combustible Fired Per Hour	Dry Coal Per Sq.Ft. of Grate Per Hour	Dry Coal Per Sq.Ft. of Heating Surface Per Hour
		Cal.	235	236	338	Cal.	339	Cal.
801	80–35–F	180	3861	3611	1287	1204	25.79	.429
802	80–45–F	180	5247	4888	1749	1629	35.05	.583
805	160–35–F	180	7071	6668	2357	2223	47.24	.786
809	240–35–F	120	6048	5711	3024	2856	60.61	1.008
806	160–45–F	180	9338	8739	3113	2913	62.38	1.037
813	280–35–F	90	5213	4830	3475	3220	69.64	1.158
814	280–40–F	60	3889	3679	3889	3679	77.94	1.296
815	320–40–F	60	4928	4596	4928	4596	98.76	1.642
807	160–55–F	180	14639	13632	4880	4544	97.79	1.626
811	240–50–F	120	11603	10808	5802	5404	116.25	1.934
812	240–55–F	105.6	11787	11110	6694	6312	134.15	2.231

The maximum boiler horse power developed was 1,421.

The horse power developed per square foot of heating surface ranged from .145 to .474.

The maximum horse power developed per square foot of grate surface is equivalent to about one horse power for each .035 square foot of grate surface.

COAL AND RATE OF COMBUSTION—TABLE 804.

The total dry coal fired ranged from 3,861 pounds to 14,639 pounds, and the amount per hour from 1,287 pounds to 6,694 pounds.

The dry coal fired per square foot of grate area per hour ranged from 25.79 pounds to 134.15 pounds. The increase in the rate of combustion was not regular.

The coal burned per square foot of heating surface per hour ranged from .429 to 2.231 pounds.

CINDERS AND SPARKS—TABLE 805.

The maximum calorific value of the cinders was 13,225 B.

TABLE No. 805—CINDERS AND SPARKS.

Identification of Test		Duration of Test, Minutes	Total in Lbs. Per Hour			Calorific Value, B.T.U. Per Lb.	
Test Number	Laboratory Designation		Cinders in Smoke-Box	Sparks from Stack	Cinders and Sparks	Of Cinders	Of Sparks
		Cal.	Cal.	Cal.	Cal.	250	251
801	80-35-F	180	——	——	——	——	——
802	80-45-F	180	——	——	——	——	——
805	160-35-F	180	6.67	58.7	65.3	12585	12372
809	240-35-F	120	6.50	85.0	91.5	12585	11945
806	160-45-F	180	1.66	198.0	199.7	11946	10239
818	280-35-F	90	6.66	86.7	93.3	13225	12799
814	280-40-F	60	4.00	206.0	210.0	12799	12585
815	320-40-F	60	8.00	238.0	246.0	12585	12372
807	160-55-F	180	2.00	147.7	149.7	11946	11519
811	240-50-F	120	4.00	167.0	171.0	12372	11945
812	240-55-F	105.6	2.27	165.9	168.2	——	12165

T. U., and the maximum calorific value of the sparks was 12,799 B. T. U.

DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES—TABLE 806.

The equations derived from Figs. 802 to 804 inclusive as explained in Chapter XIII are for this locomotive:

$$D=.066\ G \qquad (801)$$

$$T_f=3.57\ G+1835 \qquad (802)$$

$$T_s=1.75\ G+500 \qquad (803)$$

$$T_f-T_s=1.82\ G+1335 \qquad (804)$$

$$H=.095\ G+4.0 \qquad (805)$$

$$G=.549\ (T_f-T_s)-733.5 \qquad (806)$$

$$G=10.52\ H-42.1 \qquad (807)$$

$$H=.052\ (T_f-T_s)-65.68 \qquad (808)$$

TABLE No. 806—DRAFT, RATE OF COMBUSTION, SMOKE-BOX AND FIRE-BOX TEMPERATURES.

Identification of Test		Duration of Test, Minutes	Draft in inches of Water				Temperature Degrees Fahrenheit		Dry Coal Per Sq. Ft of Grate Surface Per Hour Pounds
Test Number	Laboratory Designation		In Front of Diaphragm	Back of Diaphragm	In Fire-Box	In Ash-Pan	In Fire-Box	In Smoke-Box	
		Cal.	222	223	224	225	212	207	339
801	80-35-F	180	1.40	1.10	.41	.11	1856	512	25.79
802	80-45-F	180	1.95	1.50	.69	.20	1938	536	35.05
805	160-35-F	180	2.79	1.88	.71	.22	2180	587	47.24
809	240-35.F	120	4.06	2.99	1.31	.46	1958	630	60.61
806	160-45-F	180	4.17	2.99	1.33	.47	2057	631	62.38
813	280-35-F	90	4.77	3.45	1.47	.53	1946	635	69.64
814	280-40-F	60	6.51	4.54	1.11	.55	2259	675	77.94
815	320-40-F	60	6.68	4.49	1.14	.58	2174	678	98.76
807	160-55-F	180	6.29	4.41	1.78	.54	2111	672	97.79
811	240-50-F	120	7.41	5.09	2.22	.64	2314	716	116.25
812	240-55-F	105.6	8.86	6.04	1.82	.79	2339	743	134.15

TABLE No. 807—EVAPORATIVE PERFORMANCE.

Identification of Test		Duration of Test, Minutes	Evaporative Performance			B. T. U. Per Lb. of Dry Coal	Efficiency of Boiler
Test Number	Laboratory Designation		Total Water Divided by Total Coal	Equivalent Evaporation Per Lb. of Dry Coal	Equivalent Evaporation Per Lb. of Combustible		
		Cal.	Cal.	347	348	248	350
801	80-35-F	180	9.59	11.68	12.49	14976	75.34
802	80-45-F	180	8.77	10.69	11.48	14967	69.00
805	160-35-F	180	8.39	10.20	10.82	15067	65.38
809	240-35-F	120	8.12	9.91	10.49	14962	63.95
806	160-45-F	180	8.19	10.01	10.66	15076	64.05
813	280-35-F	90	7.78	9.51	10.27	14862	61.81
814	280-40-F	60	8.03	9.70	10.25	15085	62.11
815	320-40-F	60	6.61	7.91	8.48	14967	51.02
807	160-55-F	180	6.84	8.17	8.78	14876	53.05
811	240-50-F	120	6.33	7.72	8.28	14958	49.83
812	240-55-F	105.6	6.08	7.32	7.77	15081	46.89

The fire-box temperatures ranged from 1,856 to 2,339 degrees Fahr., and the smoke-box temperatures ranged from 512 to 743 degrees Fahr.

EVAPORATIVE PERFORMANCE—TABLE 807.

The equivalent evaporation per pound of dry coal ranged from 11.68 pounds to 7.32 pounds.

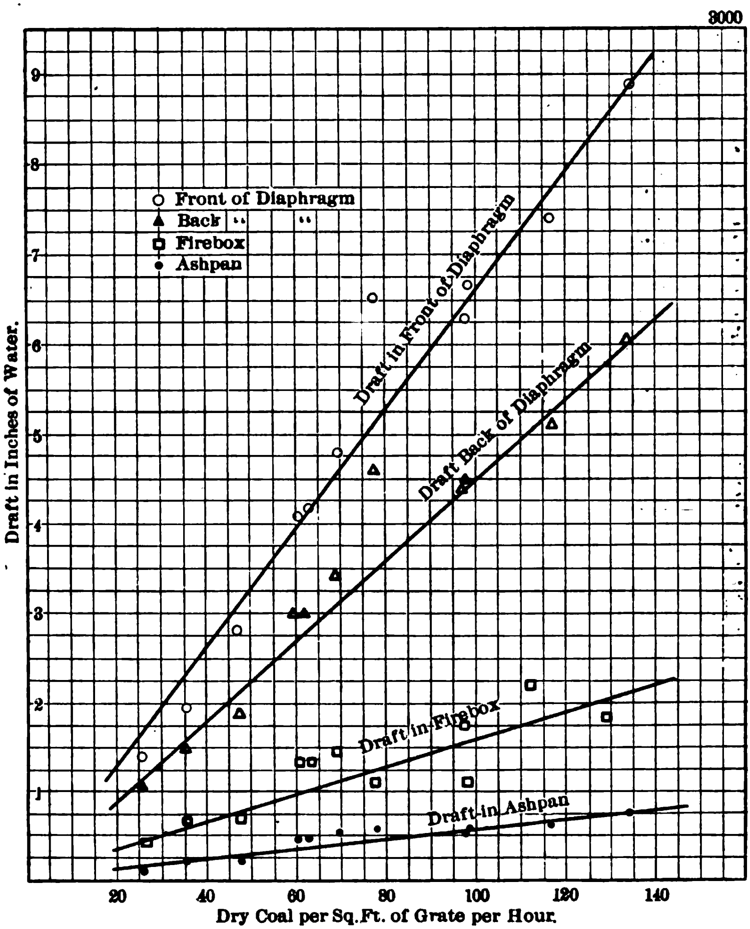


Fig. 802.— Draft and Rate of Combustion.

The heating value of the coal was practically uniform for all the tests.

The efficiency of the boiler dropped rapidly as the rate of

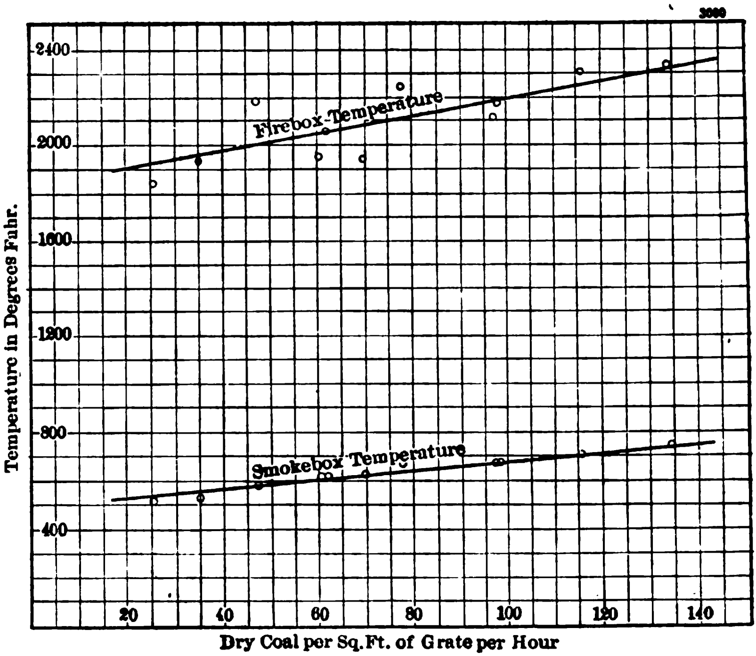


Fig. 803.— Fire-box and Smoke-box Temperatures.

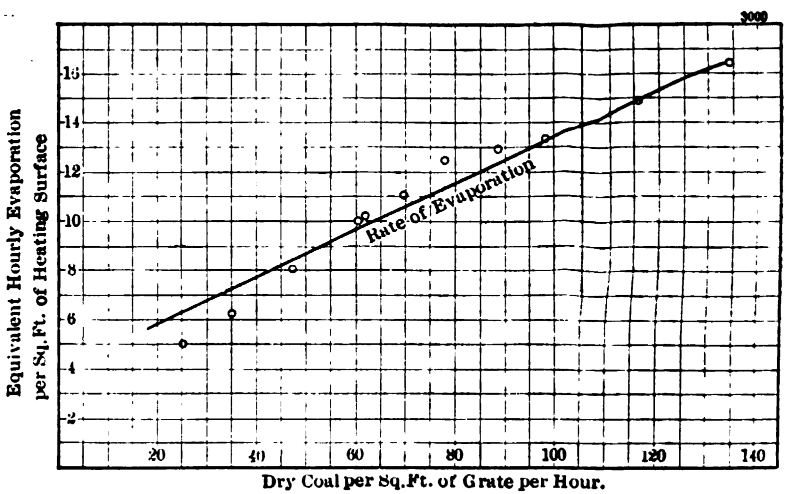


Fig. 804.— Rates of Combustion and Evaporation.

evaporation increased, the range being between the rather wide limits of 75.34 per cent. and 46.89 per cent.

The relation between E and H for this locomotive is:

$$E = 13.8 - .412\ H \qquad (809)$$

SMOKE-BOX GASES—TABLE 808.

While the percentage of oxygen showed some irregularities, nevertheless there was a tendency for it to decrease as the rate of evaporation increased—the range for the several tests being between the limits of 6.73 per cent. and 3.13 per cent.

The percentages of CO increased as the rate of evaporation

TABLE No. 808—SMOKE-BOX GASES.

Identification of Test		Duration of Test, Minutes	Analysis of Smoke-Box Gases				Calorific Value of Coal as Fired	Per Cent. of Heat in Coal, Lost by Presence of CO
Test Number	Laboratory Designation		Per Cent. Oxygen O	Per Cent. Carbon Monoxide CO	Per Cent. Carbon Dioxide CO_2	Per Cent. Nitrogen N		
		Cal.	253	254	255	256	Cal.	Cal.
801	80-35-F	180	6.73	.00	12.03	81.24	14825	0
802	80-45-F	180	6.13	.00	12.27	81.60	14826	0
805	160-35-F	180	6.63	.07	12.10	81.20	14932	.33
809	240-35-F	120	5.00	.07	13.20	81.73	14828	.30
806	160-45-F	180	4.37	.10	13.63	81.90	14935	.42
813	280-35-F	90	3.70	.10	14.00	82.20	14721	.41
814	280-40-F	60	5.85	.05	12.50	81.60	14932	.23
815	320-40-F	60	4.80	.10	13.55	81.55	14826	.42
807	160-55-F	180	4.07	.30	13.67	81.96	14720	1.25
811	240-50-F	120	5.03	.23	12.97	81.77	14827	1.00
812	240-55-F	105.6	3.13	.63	13.90	82.34	14923	.25

increased—the range for this locomotive being between the limits of 0.0 per cent. and .63 per cent.

The carbon dioxide, CO_2, ranged from 12.03 per cent. to 14.00 per cent.

The heat lost by imperfect combustion ranged from 0.0 per cent. to 1.25 per cent.

PERFORMANCE OF ENGINES.

MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION—TABLE 810.

The best performance of the engines was at 36.3 per cent.

TABLE No. 809—GENERAL ENGINE CONDITIONS.

Identification of Test		Duration of Test, Minutes	Revolutions Per Minute	Speed in Miles Per Hour	Cut-off, Per Cent. of Stroke H. P. Cylinder	Steam Pressure	
Test Number	Laboratory Designation					In Boiler Lbs. Per Sq. In.	In Branch-Pipe Lbs. Per Sq. In.
		Cal.	198	199	268 to 271	217	220
801	80–35–F	180	79.82	18.72	36.0	209.4	207.0
802	80–45–F	180	80.00	18.76	45.9	210.8	207.9
805	160–35–F	180	160.00	37.52	36.3	222.2	218.6
806	160–45–F	180	160.00	37.52	43.7	220.4	216.0
807	160–55–F	180	160.00	37.52	57.1	221.4	216.3
809	240–35–F	120	240.00	56.29	32.2	218.7	214.6
811	240–50–F	120	239.99	56.28	46.6	219.6	212.8
812	240–55–F	105.6	240.00	56.29	53.7	212.3	205.2
813	280–35–F	90	280.11	65.69	32.2	220.0	215.6
814	280–40–F	60	279.97	65.66	38.2	220.2	214 1
815	320–40–F	60	320.00	75.05	41.0	222.3	215.8

TABLE No. 810—MEAN EFFECTIVE PRESSURE, INDICATED HORSE POWER AND STEAM CONSUMPTION.

Identification of Test		Duration of Test, Minutes	Mean Effective Pressure Lbs. Per Sq. Inch		Indicated Horse Power	Dry Steam Per Indicated Horse Power Hour, Lbs.
Test Number	Laboratory Designation		H. P. Cyl.	L. P. Cyl.		
		Cal.	Cal.	Cal.	379	381
801	80–35–F	180	63.2	29.1	567.4	20.78
802	80–45–F	180	83.3	35.2	714.4	20.47
805	160–35–F	180	56.8	23.7	967.0	19.60
806	160–45–F	180	75.1	30.2	1253.0	19.95
807	160–55–F	180	93.5	34.4	1490.5	21.57
809	240–35–F	120	43.1	19.3	1142.8	21.05
811	240–50–F	120	68.2	25.1	1629.8	22.18
812	240–55–F	105.6	67.5	25.7	1641.4	24.14
813	280–35–F	90	39.5	16.9	1192.3	22.27
814	280–40–F	60	44.9	19.6	1368.9	22.19
815	320–40–F	60	37.3	16.2	1335.7	23.51

high pressure cut-off and 160 revolutions per minute (about 37½ miles per hour), under which conditions the steam consumption was 19.60 pounds per indicated horse power hour.

The highest indicated horse power was 1,641.4, which was obtained at 55 per cent. high pressure cut-off and a nominal speed of 240 revolutions per minute.

PERFORMANCE OF LOCOMOTIVE.

DYNAMOMETER RECORDS—TABLE 811.

The maximum average recorded draw-bar pull was 12,780

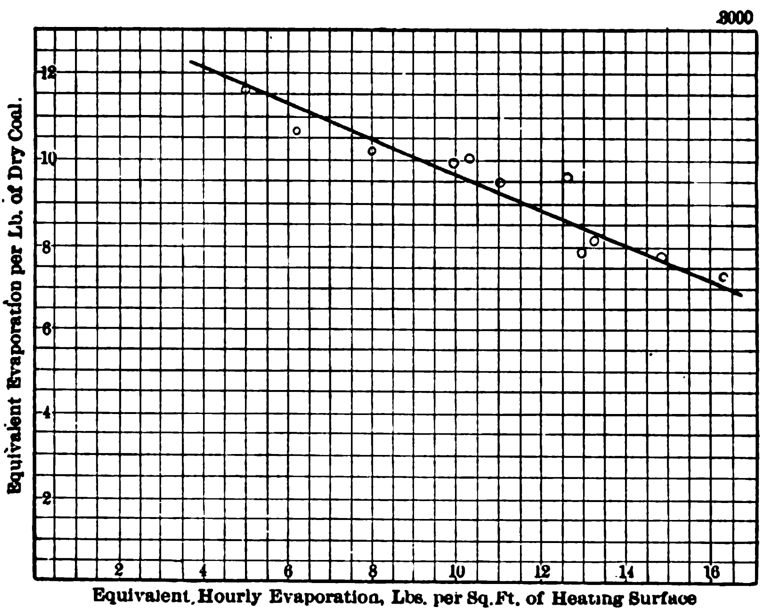


Fig. 805.—Rate of Evaporation and Evaporation per Lb. of Coal.

pounds at a nominal speed of 160 revolutions per minute and a nominal high pressure cut-off of 55 per cent.

The maximum dynamometer horse power was 1,475.6, which was obtained at a nominal speed of 240 revolutions per minute and a nominal cut-off of 55 per cent.

The general tendency was for the coal per dynamometer horse power hour to increase as the speed increased. The mini-

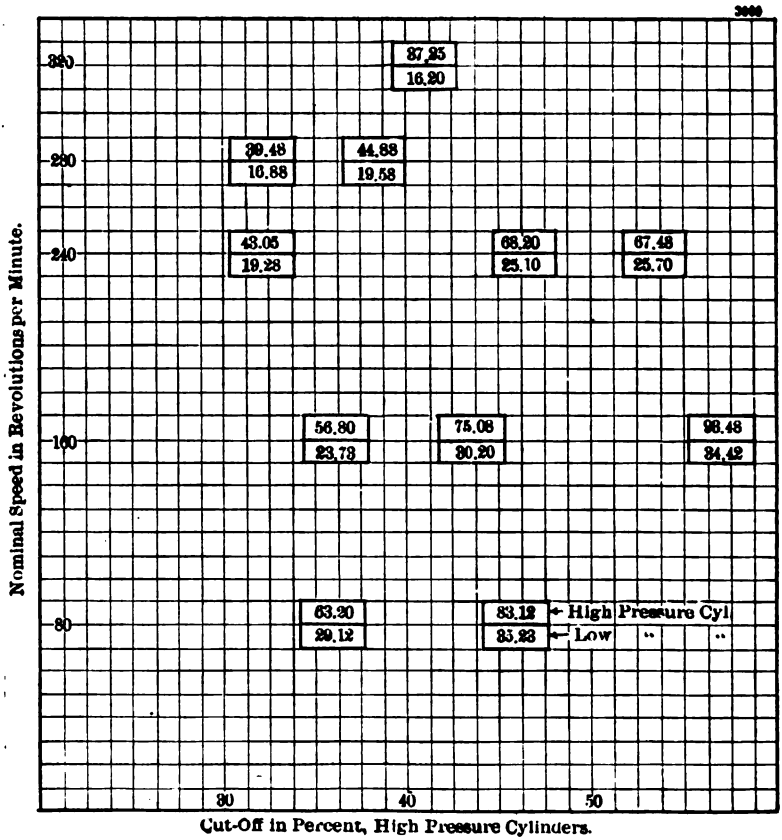


Fig. 806.— Mean Effective Pressure.

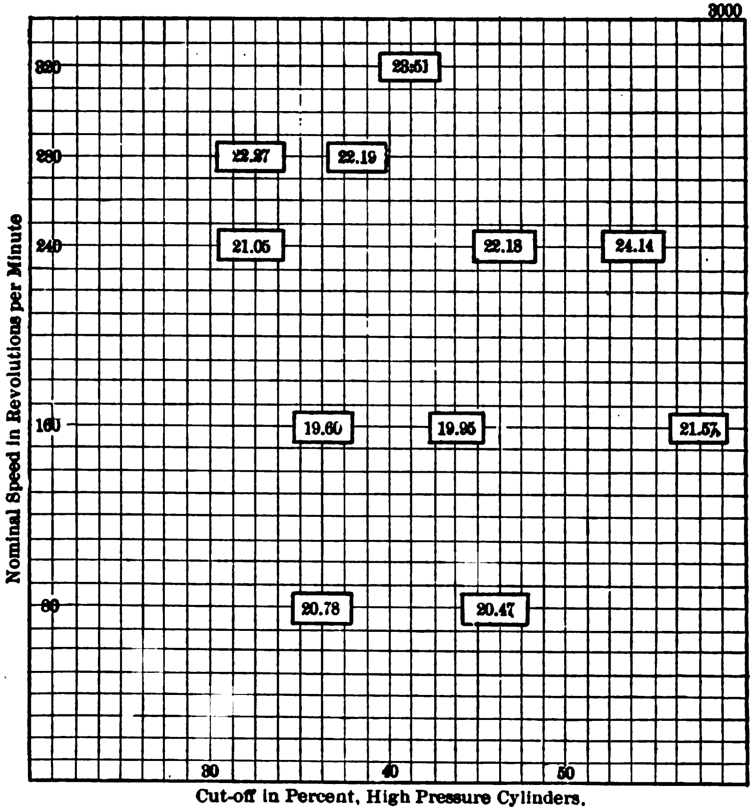
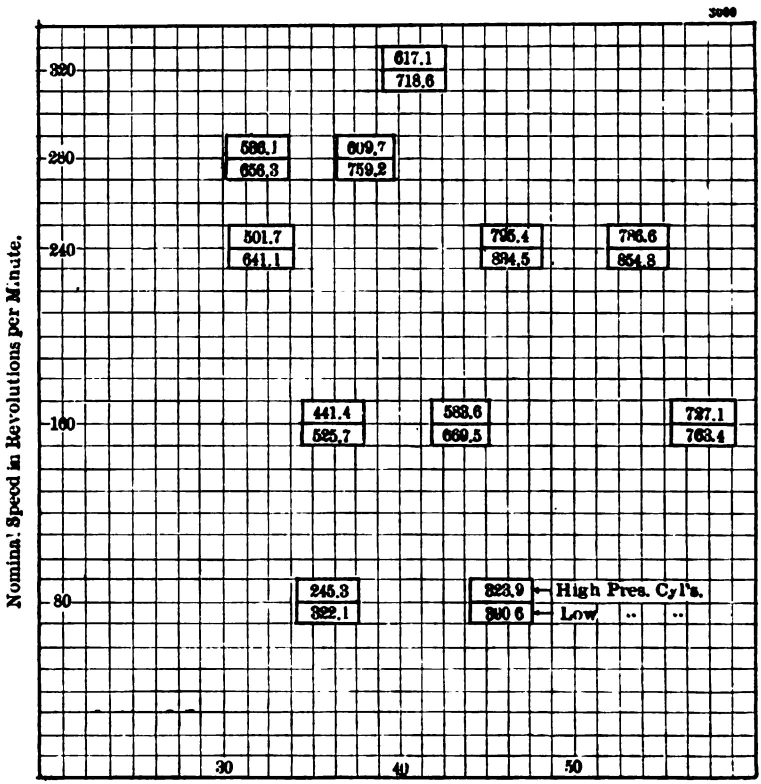


Fig. 807.— Dry Steam per I. H. P. Hour.

mum coal rate obtained was 2.53 pounds and the maximum rate was 4.65 pounds per dynamometer horse power hour.

The lowest steam consumption was 21.19 pounds per dynamometer horse power hour, which was obtained at a nominal speed



Cut-Off in Percent, High Pressure Cylinders.

Fig. 808.— Total Indicated Horse Power.

of 160 revolutions per minute, and a nominal high pressure cut-off of 35 per cent.

MACHINE FRICTION—TABLE 812.

The machine efficiency ranged from 68.47 per cent. to 93.95 per cent. At a nominal speed of 80 revolutions per minute and a nominal cut-off of 35 per cent., the machine efficiency was 68.47

TABLE No. 811—DYNAMOMETER RECORDS.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Draw-Bar Pull in Pounds	Dynamometer Horse Power	Dry Coal Per D. H. P. Hour	Dry Steam Per D. H. P. Hour
		Cal.	265	383	384	385
801	80-35-F	180	7781	388.5	3.17	30.35
802	80-45-F	180	12121	606.5	2.75	24.11
805	160-35-F	180	8940	894.6	2.53	21.19
806	160-45-F	180	11766	1177.3	2.60	21.23
807	160-55-F	180	12780	1278.8	3.77	25.14
809	240-35-F	120	6422	964.0	3.08	24.96
811	240-50-F	120	9796	1470.1	3.90	24.59
812	240-55-F	105.6	9831	1475.6	4.49	26.86
813	280-35-F	90	5530	968.9	3.53	27.42
814	280-40-F	60	6788	1188.5	3.23	25.55
815	320-40-F	60	5224	1045.4	4.65	30.04

TABLE No. 812—MACHINE FRICTION.

Identification of Test: Test Number	Identification of Test: Laboratory Designation	Duration of Test, Minutes	Machine Friction in: Horse Power	Machine Friction in: Draw-Bar Pull Pounds	Machine Efficiency Per Cent.
		Cal.	395	397	396
801	80-35-F	180	178.91	3585	68.47
802	80-45-F	180	107.97	2159	84.89
	Average		143.44	2872	
805	160-35-F	180	72.44	724	92.51
806	160-45-F	180	75.73	757	93.95
807	160-55-F	180	211.73	2116	85.80
	Average		119.96	1199	
809	240-35-F	120	178.85	1192	84.35
811	240-50-F	120	159.71	1064	90.20
812	240-55-F	105.6	165.88	1105	89.90
	Average		168.15	1120	
813	280-35-F	90	223.44	1276	81.25
814	280-40-F	60	180.36	1030	86.83
	Average		201.90	1153	
815	320-40-F	60	290.28	1450	78.27

per cent. At the same speed, but with a nominal cut-off of 45 per cent., the machine efficiency was 84.89 per cent.

The low efficiency of test No. 801 is thought to have been due to the locomotive having been standing in the Transportation Building for a number of months before the tests were begun. Test No. 801 being the first of the series, it is quite certain that the bearings were not in as favorable condition for this test as they were for those following.

MAXIMUM POWER OF LOCOMOTIVE.

The maximum evaporative power of the boiler, as disclosed

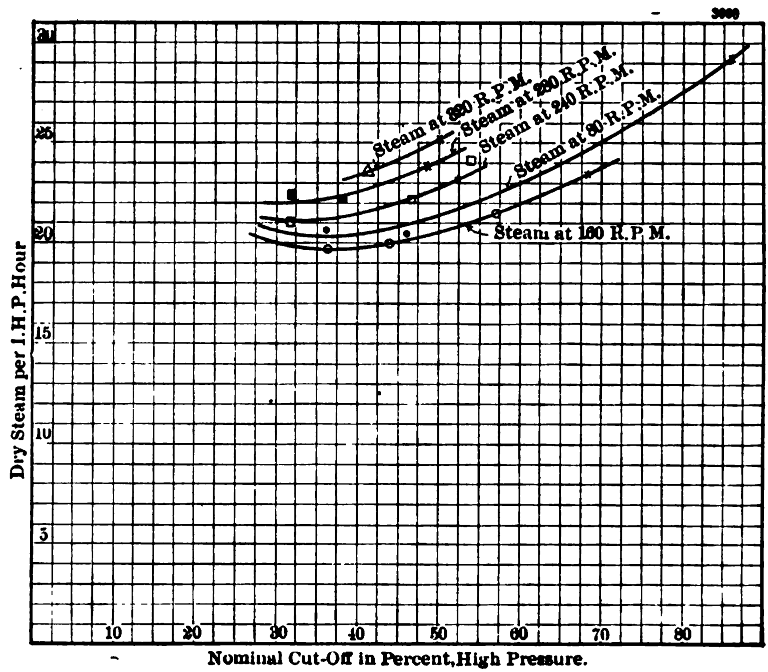


Fig. 809.— Steam Consumption.

by these tests, is between 38,000 and 39,000 pounds of steam per hour, which is equivalent to a rate of evaporation of between 15 and 16 pounds per square foot of heating surface per hour.

In Fig. 811 is shown the maximum draw-bar pull of this locomotive as limited by the cylinder power and the maximum evaporation of the boiler. The method of plotting these curves is as given in Chapter XIII, page 143.

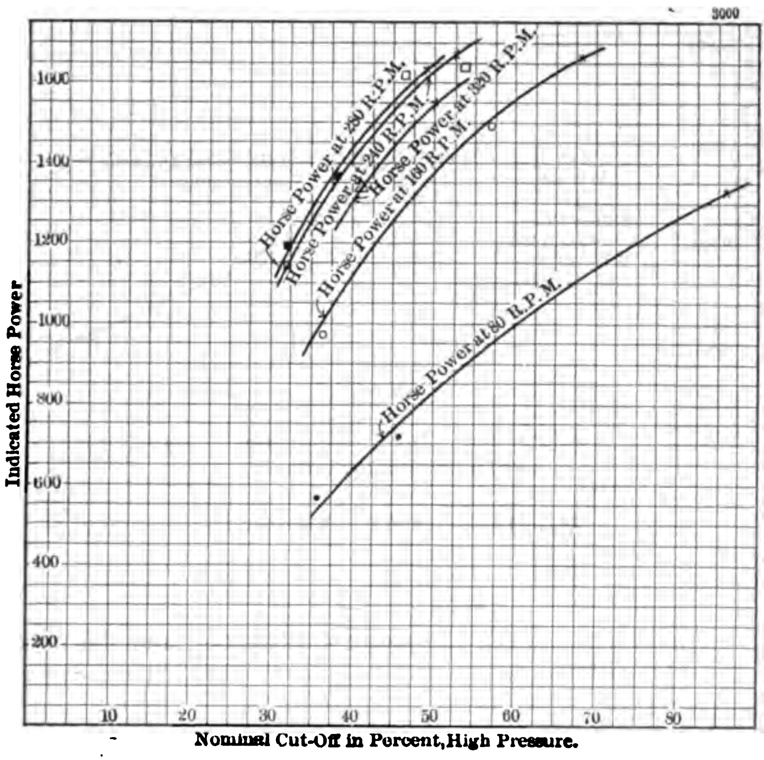


Fig. 810.—Indicated Horse Power.

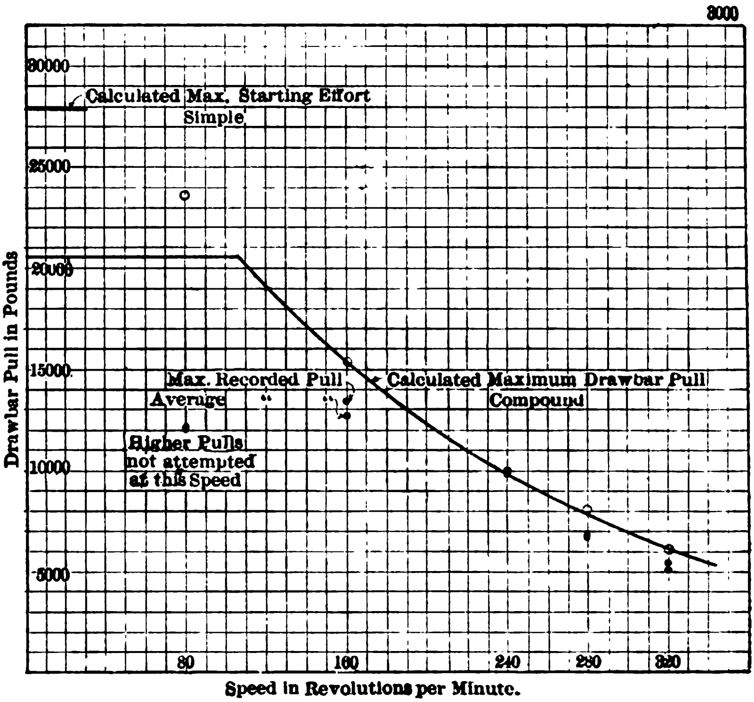


Fig. 811.— Maximum Draw-bar Pull.

The critical cut-off, the steam consumption and the maximum cylinder horse power as derived from Figs. 809 and 810 are as follows:

NOMINAL SPEED IN R. P. M.	CUT-OFF IN PER CENT.	STEAM PER INDICATED HORSE POWER HOUR	MAXIMUM CYLINDER HORSE POWER
80	86	29.20	1330
160	68	23.40	1665
240	52.5	23.20	1670
280	48.5	23.80	1625
320	50	25.20	1545

Reducing the maximum cylinder horse power to equivalent draw-bar pull and subtracting the average frictional draw-bar pull gives:

Speeds in R. P. M.	Maximum Estimated Draw-Bar Pull, Pounds.
80	23712
160	15451
240	10002
280	8125
320	6268

The lowest speed at which the full power of the boiler can be utilized is between 100 and 110 revolutions.

APPENDIX 800.

The appendix contains:

1. Description, dimensions and proportions of the locomotive. (pp. 637 to 642 inclusive.)

2. Summary of average results of tests. (pp. 643 to 653 inclusive.)

3. Graphical running logs showing boiler pressure, total water, total coal, revolutions per minute, total revolutions and draw-bar pull for each test. Each diagram was plotted during the test to which it refers. (pp. 654 to 659 inclusive.)

4. Plots showing relations between important items of the tests. (pp. 660 to 675 inclusive.)

5. Vibration diagrams. (pp. 676 to 679 inclusive.)

6. Typical indicator diagrams. A representative set of diagrams from each test is shown. (pp. 680 to 683 inclusive.)

7. A typical dynamometer diagram for each nominal speed. (pp. 684 and 686.)

8. Illustrations of the locomotive showing important details and location of testing instruments.

Description, Dimensions and Proportions of New York Central I1 Atlantic (4-4-2) Type Locomotive No. 3000.

Built by the American Locomotive Co., Schenectady, N. Y., 1904.

DRIVING WHEELS.

1	Number of pairs	2
2	Approximate diameter, inches	79

MEASURED CIRCUMFERENCE, FEET.

3	Right, No. 1	20.638
4	" " 2	20.640
5	" " 3	——
6	" " 4	——
7	" " 5	——
8	Left, " 1	20.636
9	" " 2	20.635
10	" " 3	——
11	" " 4	——
12	" " 5	——
13	Average	20.637

ENGINE TRUCK WHEELS.

14	Number	4
15	Diameter, inches	36.48

TRAILING WHEELS.

16	Diameter, inches	50.0

WHEEL BASE, FEET.

17	Driving wheel base	7.00
18	Total wheel base	27.75
19	Gauge of wheels, in inches	56.00

WEIGHT OF ENGINE WITH WATER AT SECOND GAUGE COCK AND NORMAL FIRE, IN POUNDS.

20	On truck	50,000
21	" 1st drivers	55,100
22	" 2nd "	54,900
23	" 3rd "	——
24	" 4th "	——
25	" 5th "	——
26	" trailers	40,000
27	Total	200,000
28	" on drivers	110,000

CYLINDERS.

29	High pressure, number	2
30	Low " "	2
31	Arrangement, L. P. outside ; H. P. inside ; Cole comp.	

DIAMETER, INCHES.

32	High pressure, right	15.510
33	" " left	15.512
34	Low " right	26.006
35	" " left	26.013

STROKE OF PISTON, FEET.

36	High pressure, right	2.163
37	" " left	2.163
38	Low " right	2.166
39	" " left	2.166

CLEARANCE, PER CENT. OF PISTON DISPLACEMENT.

40	H. P., right, head end	17.1
41	" " crank "	16.9
42	" left, head "	16.7
43	" " crank "	16.8
44	L. P., right, head "	6.7
45	" " crank "	6.5
46	" left, head "	6.4
47	" " crank "	6.5

RECEIVER, CUBIC FEET.

48	Volume, right side	6.11
49	" left "	6.10

STEAM PORTS, INCHES.

(*For piston valves the length equals the circumference of inside of bushing minus the sum of the widths of bridges.*)

50	H. P. admission, right, head end, length	33.02
51	" " " " " width	2.01
52	" " " crank " length	33.36
53	" " " " " width	2.01
54	" " left, head " length	33.30
55	" " " " " width	2.01
56	" " " crank " length	34.08
57	" " " " " width	2.00
58	L. P. " right, head " length	33.25
59	" " " " " width	2.13
60	" " " crank " length	33.35
61	" " " " " width	2.13
62	" " left, head " length	33.14
63	" " " " " width	2.13
64	" " " crank " length	33.42
65	" " " " " width	2.13
66	H. P. exhaust, right, length	exhausts into receiver
67	" " " width	
68	" " left, length	
69	" " " width	
70	L. P. " right, length	44.01

71	L. P. exhaust, right, width	21.50
72	" " left, length	43.98
73	" " " width	21.51

PISTON RODS, DIAMETER, INCHES.

74	High pressure, right	3.000
75	" " left	3.000
76	Low " right	3.002
77	" " left	3.002

TAIL RODS, DIAMETER, INCHES.

78	High pressure, right	——
79	" " left	——
80	Low " right	——
81	" " left	——

VALVES.

82	Type	piston
83	Design	American Locomotive Co.
84	Per cent. of balanced to total area	H.P. 91.22; L.P. 90.79
85	Type of link motion	Stephenson

GREATEST VALVE TRAVEL, INCHES.

86	High pressure, right	5.985
87	" " left	6.015
88	Low " right	5.985
89	" " left	6.015

OUTSIDE LAP OF VALVE, INCHES.

90	High pressure, right, head end	.99
91	" " " crank "	.99
92	" " left, head "	1.01
93	" " " crank "	1.01
94	Low " right, head "	1.01
95	" " " crank "	.94
96	" " left, head "	.97
97	" " " crank "	.99

INSIDE LAP OF VALVE, INCHES.

98	High pressure, right, head end,	negative	.32
99	" " " crank "	"	.32
100	" " left, head "	"	.34
101	" " " crank "	"	.33
102	Low " right, head "	"	.40
103	" " " crank "	"	.33
104	" " left, head "	"	.36
105	" " " crank "	"	.38

MISCELLANEOUS.

106	Cylinder lagging material	Magnesia
107	" jacket "	sheet iron
108	Lead, forward motion,	H. P., 0.; L. P., 0.;
109		
110		
111		
112		Right L. P. crank leads left L. P. crank

BOILER.

113	Type	Straight top, wide fire box
114	Outside diameter, 1st ring, inches	72.25

TUBES.

115	Number	390
116	Outside diameter, inches	2
117	Thickness, inches	.125
118	Length between tube sheets, inches	191.295
119	Total fire area, square feet	6.514
120	Serve tubes, number of ribs	——
121	" " sq. in, of inside surface in one in. of length	——
122		
123		
124	Boiler pressure, pounds per sq. in.	220

SUPERHEATER.

125	Number of tubes	——
126	Outside diameter, inches	——
127	Thickness, inches	——
128	Length of tubes, inches	——
129		
130		
131		

FIRE-BOX (SIZE INSIDE, INCHES.)

132	Length	94.90
133	Width	75.04
134	Depth, front end	73.38
135	" back "	65.94
136	Volume, cubic feet (less arch and tubes)	220.30
137	Air inlets to ash pan, (dampers closed) sq. ft	1.23
138	" " " " " (" open) " "	4.85
139		
140		

FIRE DOORS.

141	Number	2
142	Area, square feet	2.45
143		

GRATES.

144	Style	rocking, finger
145	Total area, square feet	49.90
146	" " dead grates, square feet	0
147	Width of air spaces, inches	.75

AIR INLET AREAS, SQUARE FEET.

148	Through fire box sides	.0
149	" grates	17.74
150	" fire doors	1.02
151	Total air inlets, (148), (149) and (150)	18.76
152	Ratio " " (149) to grate area (145)	.356
153	" " " (151) " " " (145)	.376

HEATING SURFACE, SQUARE FEET.

154	Of the tubes, water side	3255.27
155	" " " fire "	2848.36
156	" " firebox, fire side, including arch tubes	151.69
157	" " superheater, fire side	——
158	Total, based on inside of firebox and inside of tubes	3000.05
159	Total, based on inside of firebox and outside of tubes	3406.96

BOILER VOLUMES.

(With water surface at level of second gauge cock.)

160	Water space, cubic feet	331.666
161	Steam " " "	77.406

EXHAUST NOZZLE.

162	Double or single	single
163	Size of right, inches	5.625
164	" " left, "	
165	Area of right, square inches	
166	" " left, " "	
167	Total area, square inches	24.236

REVERSE LEVER.

168	H. P. cylinder, notches forward of centre	23
169	L. P. " " " " "	
170	5.5 notches blank from center to twenty-third notch	

RATIOS.

171	Heating surface (158) to grate area (145)......	60.12
172	Fire area through tubes (119) to grate area (145)	.136
173	Firebox heating surface (156) to grate area (145)	3.04
174	Tube surface (155) to firebox heating surface (156)......................................	18.77
175	Firebox volume (136) to grate area (145)......	4.41
176	....	
177	....	
178	....	

CONSTANT FOR DYNAMOMETER HORSE POWER.

(*power developed at one R. P. M. when pull is one pound.*)

179	....	.0006254

CONSTANTS FOR INDICATED HORSE POWER

(*power developed at one R. P. M. and one pound M. E. P.*)

180	High	pressure	cylinder,	right,	head end	....	.01238
181	"	"	"	"	crank "	....	.01192
182	"	"	"	left,	head "	....	.01239
183	"	"	"	"	crank "	....	.01192
184	Low	"	"	right,	head "	....	.03486
185	"	"	"	"	crank "	....	.03440
186	"	"	"	left,	head "	....	.03488
187	"	"	"	"	crank "	....	.03442

PISTON DISPLACEMENT, CUBIC FEET.

188	High	pressure	cylinder,	right,	head end	....	2.8380
189	"	"	"	"	crank "	....	2.7318
190	"	"	"	left,	head "	....	2.8387
191	"	"	"	"	crank "	....	2.7325
192	Low	"	"	right,	head "	....	7.9898
193	"	"	"	"	crank "	....	7.8833
194	"	"	"	left,	head "	....	7.9941
195	"	"	"	"	crank "	....	7.8876

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Duration of Test, Hours	Speed: Revolutions: Total	Speed: Revolutions: Average Per Minute	Speed: Equivalent: Speed in Miles Per Hour	Speed: Equivalent: Piston Speed in Feet Per Minute	Position of Levers: Reverse, Notches From Front End	Position of Levers	Position of Levers: Throttle Notches	Coal Loss due to Steam Loss Lbs. Per Hour	
		196	197	198	199	200	201	202	203	204	205
801	80–35–F	3.00	14367	79.82	18.72	345.5	23		Full	55	
802	80–45–F	3.00	14400	80.00	18.76	346.3	21		"	80	
805	160–35–F	3.00	28800	160.00	37.52	692.6	23		"	94	
806	160–45–F	3.00	28800	160.00	37.52	692.6	21		"	53	
807	160–55–F	3.00	28800	160.00	37.52	692.6	19		"	65	
809	240–35–F	2.00	28800	240.00	56.29	1039.1	23		"	53	
811	240–50–F	2.00	28799	239.99	56.28	1039.0	20		"	69	
812	240–55–F	1.76	25361	240.00	56.29	1039.1	19		"	69	
813	280–35–F	1.50	25210	280.11	65.69	1212.5	23		"	55	
814	280–40–F	1.00	16798	279.97	65.66	1212.0	22		"	54	
815	320–40–F	1.00	19200	320.00	75.05	1385.3	22		"	67	

Test Number	Laboratory Designation	Temperature, Degrees Fahrenheit, of: Smoke Box: By Thermometer	Smoke Box: By Pyrometer	Laboratory: Dry Bulb	Laboratory: Wet Bulb	Steam in Branch Pipe	Feed Water	Fire Box by Pyrometer		Horizontal Vibration at Front of Engine Inches		Steam lost from Boiler, etc. Lbs. per hour
		206	207	208	209	210	211	212	213	214	215	216
801	80–35–F		512	51.7	45.2	390.4	48.8	1856		—		528
802	80–45–F		536	54.3	46.0	390.8	52.2	1938		—		697
805	160–35–F		587	50.1	43.0	394.9	50.0	2180		—		783
806	160–45–F		631	41.3	37.8	393.9	49.3	2057		.24		429
807	160–55–F		672	50.4	44.8	394.0	49.6	2111		.21		433
809	240–35–F		630	52.9	47.7	393.3	50.0	1958		.12		426
811	240–50–F		716	42.9	39.7	392.7	49.0	2314		.12		432
812	240–55–F		748	43.5	38.5	389.7	49.5	2339		.12		412
813	280–35–F		635	50.9	41.2	393.7	49.0	1946		.11		428
814	280–40–F		675	49.3	43.1	393.2	49.0	2259		.10		429
815	320–40–F		678	51.5	49.3	393.8	49.5	2174		.11		431

For date of test, see item 407.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Pressure, Pounds per Square Inch: In Boiler: Average	Pressure, Pounds per Square Inch: In Boiler: Maximum	Pressure, Pounds per Square Inch: In Boiler: Minimum	Pressure, Pounds per Square Inch: In Branch Pipe	Pressure, Pounds per Square Inch: Air in Laboratory Barometric	Draft, Inches of Water: In Smoke Box: Front of Diaphragm.	Draft, Inches of Water: In Smoke Box: Back of Diaphragm.	Draft, Inches of Water: In Fire Box	Draft, Inches of Water: In Ash Pan	Injectors: Hours in Action: Total, Right	Injectors: Hours in Action: Total, Left
		217	218	219	220	221	222	223	224	225	226	227
801	80–35–F	209.4	211.5	206.0	207.0	14.549	1.40	1.10	.41	.11	.21	1.81
802	80–45–F	210.8	213.5	207.9	207.9	14.601	1.95	1.50	.69	.20	.00	1.97
805	160–35–F	222.2	225.8	215.1	213.6	14.569	2.79	1.88	.71	.22	.00	2.96
806	160–45–F	220.4	224.9	216.8	216.0	14.536	4.17	2.99	1.33	.47	.00	2.84
807	160–55–F	221.4	225.0	214.3	216.3	14.443	6.29	4.41	1.78	.54	1.55	1.45
809	240–35–F	218.7	221.8	215.2	214.6	14.488	4.06	2.99	1.31	.46	.00	2.00
811	240–50–F	219.6	225.0	214.8	212.8	14.510	7.41	5.09	2.22	.64	1.93	.03
812	240–55–F	212.3	221.1	201.3	205.2	14.524	8.86	6.04	1.82	.79	1.76	.00
813	280–35–F	220.0	220.6	218.6	215.6	14.509	4.77	3.45	1.47	.53	.00	1.50
814	280–40–F	220.2	224.2	214.5	214.1	14.508	6.51	4.54	1.11	.55	1.00	.05
815	320–40–F	222.3	226.0	216.9	215.8	14.514	6.68	4.49	1.14	.58	1.00	.00

Test Number	Laboratory Designation	Quality of steam: In Dome	Quality of steam: In Branch Pipe	Quality of steam: Degrees of Superheat in Branch Pipe	Quality of steam: Factor of Correction (Dome)	Coal, Sparks and Ash, Pounds: Coal Fired: Kind	Coal, Sparks and Ash, Pounds: Coal Fired: Total	Coal, Sparks and Ash, Pounds: Coal Fired: Per Cent of Moisture	Coal, Sparks and Ash, Pounds: Total: Dry Coal Fired	Coal, Sparks and Ash, Pounds: Total: Combustible by Analysis	Coal, Sparks and Ash, Pounds: Total: Ash by Analysis
		228	229	230	231	232	233	234	235	236	237
801	80–35–F	.9826	.9821	0	.98770	Bituminous	3901	1.01	3861	3611	250
802	80–45–F	.9835	.9824	0	.98830	"	5297	.95	5247	4888	359
805	160–35–F	.9830	.9842	0	.98804	"	7135	.90	7071	6668	403
806	160–45–F	.9827	.9837	0	.98754	"	9428	.96	9388	8789	599
807	160–55–F	.9499	.9570	0	.96472	"	14796	1.06	14639	13632	1006
809	240–35–F	.9822	.9831	0	.98747	"	6104	.92	6048	5711	338
811	240–50–F	.9819	.9845	0	.98726	"	11709	.89	11603	10808	796
812	240–55–F	.9627	.9653	0	.97367	"	11913	1.06	11787	11110	677
813	280–35–F	.9827	.9831	0	.98793	"	5264	.97	5213	4830	383
814	280–40–F	.9653	.9727	0	.97561	"	3929	1.02	3889	3679	210
815	320–40–F	.9530	.9648	0	.96700	"	4976	.95	4928	4596	332

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R, Co.

Test Number	Laboratory Designation	Coal, Sparks and Ash, Lbs. Total: Cinders Collected in Smoke Box	Total: Sparks Discharged From Stack	Total: Cinders and Sparks	Analysis of Coal, Per Cent: Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur; Determined Separately		
		238	239	240	241	242	243	244	245	246	247
801	80-35-F	—	—	—	76.04	16.53	1.01	6.42	1.19		
802	80-45-F	—	—	—	75.74	16.53	.95	6.78	.83		
805	160-35-F	20	176	196	77.06	16.39	.90	5.65	.78		
806	160-45-F	5	594	599	75.89	16.80	.96	6.35	.88		
807	160-55-F	6	443	449	76.04	16.10	1.06	6.80	.71		
809	240-35-F	13	170	183	76.77	16.78	.92	5.53	.78		
811	240-50-F	8	334	342	75.92	16.39	.89	6.80	.78		
812	240-55-F	4	292	296	76.56	16.70	1.06	5.68	.95		
813	280-35-F	10	130	140	75.58	16.17	.97	7.28	.84		
814	280-40-F	4	206	210	77.38	16.26	1.02	5.34	.93		
815	320-40-F	8	238	246	75.94	16.44	.95	6.67	.85		

Test Number	Laboratory Designation	Calorific Value Per Lb. of Fuel, B. T. U.: Of Dry Coal	Of Combustible	Of Cinders	Of Sparks		Analysis of Smoke Box Gases, Per Cent: Oxygen O	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N		
		248	249	250	251	252	253	254	255	256	257	258
801	80-35-F	14976	16014	—	—		6.73	.00	12.03	81.24		
802	80-45-F	14967	16066	—	—		6.13	.00	12.27	81.60		
805	160-35-F	15067	15978	12585	12372		6.63	.07	12.10	81.20		
806	160-45-F	15076	16109	11946	10239		4.37	.10	13.63	81.90		
807	160-55-F	14876	15974	11946	11519		4.07	.30	13.67	81.96		
809	240-35-F	14962	15846	12585	11945		5.00	.07	13.20	81.73		
811	240-50-F	14958	16060	12372	11945		5.03	.23	12.97	81.77		
812	240-55-F	15081	16010	—	12165		3.13	.63	13.90	82.34		
813	280-35-F	14862	16041	13225	12799		3.70	.10	14.00	82.20		
814	280-40-F	15085	15945	12799	12585		5.85	.05	12.50	81.60		
815	320-40-F	14967	16047	12585	12372		4.80	.10	13.55	81.55		

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Water, in Pounds						Dynamometer		
			Lost					Drawbar Pull in Pounds		
		Delivered to Injectors	From Boiler	From Injectors	From	Total	Delivered to Boiler and Presumably Evaporated	Average	Maximum	Minimum
		259	260	261	262	263	264	265	266	267
801	80–35–F	39751	0	2351		2351	37400	7781	9104	6986
802	80–45–F	46483	0	0		0	46483	12121	12275	11926
805	160–35–F	59896	0	0		0	59896	8940	9321	8442
806	160–45–F	77228	0	0		0	77228	11766	12200	11388
807	160–55–F	101317	0	55		55	101262	12780	13475	12050
809	240–35–F	49668	0	95		95	49573	6422	6841	6201
811	240–50–F	74117	0	25		25	74092	9796	10003	9554
812	240–55–F	72448	0	30		30	72418	9831	10003	9603
813	280–35–F	41098	0	124		124	40974	5530	5638	5398
814	280–40–F	31611	0	50		50	31561	6788	6842	6693
815	320–40–F	32931	0	25		25	32906	5224	5542	4978

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Cut-off, Per Cent. of Stroke								Release, Per Cent. of Stroke			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		268	269	270	271	272	273	274	275	276	277	278	279
801	80–35–F	37.2	36.3	36.1	34.5	36.9	35.2	37.2	34.7	64.2	57.7	63.2	58.2
802	80–45–F	47.4	44.6	48.4	43.1	42.1	43.0	46.4	46.1	71.3	67.4	71.6	64.5
805	160–35–F	37.6	37.5	37.2	32.8	38.2	34.6	36.3	36.6	67.1	63.3	65.8	60.1
806	160–45–F	46.2	41.8	46.4	40.4	46.2	43.8	47.6	44.3	76.0	70.1	76.6	69.2
807	160–55–F	60.1	54.6	60.2	53.6	57.6	54.9	58.0	54.6	80.7	75.9	81.1	74.4
809	240–35–F	32.9	31.1	32.3	32.5	39.5	38.6	41.5	36.1	65.6	61.7	63.7	61.6
811	240–50–F	46.3	44.1	49.3	46.5	50.2	51.9	56.5	51.1	77.9	75.8	79.6	74.2
812	240–55–F	55.9	52.4	——	52.7	55.7	54.1	57.4	53.8	81.0	76.4	——	76.2
813	280–35–F	32.5	30.7	32.4	33.1	40.4	35.3	38.0	34.5	65.2	60.8	62.6	60.1
814	280–40–F	38.8	36.0	40.0	38.0	44.8	40.0	43.6	39.0	68.0	65.0	66.0	63.0
815	320–40–F	42.0	39.3	42.0	40.6	48.0	48.9	49.3	44.6	65.9	64.0	65.9	62.4

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000, NEW YORK CENTRAL AND HUDSON RIVER R. R. Co.

Test Number	Laboratory Designation	Events of Stroke from Indicator Cards											
		Release, Per Cent. of Stroke				Beginning of Compression, Per Cent. of Stroke							
		Low Pressure Cylinder				High Pressure Cylinder				Low Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		280	281	282	283	284	285	286	287	288	289	290	291
801	80-35-F	62.6	61.7	63.7	62.1	38.7	31.9	39.6	32.1	20.3	18.8	21.6	17.3
802	80-45-F	68.4	68.4	69.8	68.9	33.4	27.5	33.4	27.8	19.7	17.2	21.3	17.9
805	160-35-F	65.1	62.1	64.5	63.2	30.8	24.5	25.5	20.9	27.2	27.0	27.6	23.0
806	160-45-F	74.0	73.0	74.8	71.0	20.0	16.7	17.7	16.9	22.1	20.6	24.4	18.5
807	160-55-F	79.3	77.1	78.5	75.1	22.5	17.6	21.3	17.5	18.1	16.9	18.9	14.1
809	240-35-F	68.5	66.6	70.3	65.3	23.6	16.7	22.5	17.8	26.7	22.1	25.4	17.6
811	240-50-F	79.5	78.5	81.3	76.5	19.0	14.7	17.6	16.1	20.0	17.3	18.1	13.8
812	240-55-F	77.1	76.5	78.8	75.4	26.1	21.0	——	21.8	17.3	16.1	15.6	14.2
813	280-35-F	71.0	67.1	68.4	65.2	23.8	18.5	24.0	19.2	20.0	25.2	22.8	18.6
814	280-40-F	70.6	65.8	70.6	66.6	25.8	21.6	21.2	17.6	21.2	21.6	22.2	19.0
815	320-40-F	72.8	71.7	73.1	66.6	24.9	18.6	22.1	18.4	17.1	18.9	20.4	17.9

Test Number	Laboratory Designation	Pressures from Indicator Cards								Factor of Evaporation
		Initial Pressures, Pounds Per Square Inch								
		High Pressure Cylinder				Low Pressure Cylinder				
		Right Side		Left Side		Right Side		Left Side		
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	
		292	293	294	295	296	297	298	299	300
801	80-35-F	208.0	214.2	204.8	215.1	71.8	61.1	72.7	67.6	1.2210
802	80-45-F	212.8	222.3	209.5	219.6	70.4	63.1	79.4	70.5	1.2213
805	160-35-F	227.5	233.2	224.4	231.1	71.0	62.0	80.3	63.1	1.2187
806	160-45-F	220.3	216.3	218.5	218.9	76.5	64.2	83.1	67.2	1.2250
807	160-55-F	202.7	205.3	202.1	206.4	75.8	67.6	84.4	71.2	1.2244
809	240-35-F	213.2	211.0	210.2	212.7	84.5	72.7	89.2	75.6	1.2240
811	240-50-F	213.3	205.3	208.7	210.5	91.1	74.7	92.2	79.5	1.2240
812	240-55-F	208.7	199.8	——	203.0	95.8	78.8	90.7	81.6	1.2245
813	280-35-F	211.6	211.7	213.5	217.1	93.7	78.2	96.9	81.9	1.2250
814	280-40-F	219.6	212.5	218.7	220.6	102.6	84.5	96.4	83.2	1.2250
815	320-40-F	262.3	213.6	244.1	222.9	104.1	87.1	110.1	86.3	1.2248

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Pressures from Indicator Cards: Steam Chest Pressures, Pounds Per Square Inch: High Pressure, Right Side	High Pressure, Left Side	Low Pressure, Right Side	Low Pressure, Left Side		Pressures at Cut-off, Pounds Per Square Inch: High Pressure Cylinder, Right Side, Head End	High Pressure Cylinder, Right Side, Crank End	High Pressure Cylinder, Left Side, Head End	High Pressure Cylinder, Left Side, Crank End
		301	302	303	304	305	306	307	308	309
801	80-35-F	——	——				180.4	183.0	181.2	186.2
802	80-45-F	213.9	61.4				188.0	190.8	188.1	183.9
805	160-35-F	227.5	72.9				178.3	181.7	170.9	169.8
806	160-45-F	220.1	76.4				188.0	193.8	185.4	194.9
807	160-55-F	215.6	73.1				182.3	185.2	182.7	183.8
809	240-35-F	218.2	84.5				171.2	188.5	174.3	187.1
811	240-50-F	215.5	84.5				179.1	196.6	181.3	191.0
812	240-55-F	206.3	84.1				173.5	175.2	——	173.6
813	280-35-F	220.0	85.2				176.6	192.0	178.9	188.8
814	280-40-F	220.0	90.6				177.2	190.5	174.6	185.6
815	320-40-F	224.9	91.6				160.3	176.1	161.4	175.6

Test Number	Laboratory Designation	Pressures from Indicator Cards: Pressures at Cut-off, Pounds Per Square Inch: Low Pressure Cylinder, Right Side, Head End	Low Pressure Cylinder, Right Side, Crank End	Low Pressure Cylinder, Left Side, Head End	Low Pressure Cylinder, Left Side, Crank End	Pressures at Release, Pounds Per Square Inch: High Pressure Cylinder, Right Side, Head End	High Pressure Cylinder, Right Side, Crank End	High Pressure Cylinder, Left Side, Head End	High Pressure Cylinder, Left Side, Crank End	Low Pressure Cylinder, Right Side, Head End	Low Pressure Cylinder, Right Side, Crank End	Low Pressure Cylinder, Left Side, Head End	Low Pressure Cylinder, Left Side, Crank End
		310	311	312	313	314	315	316	317	318	319	320	321
801	80-35-F	44.7	40.1	49.2	43.9	116.7	126.5	117.5	123.1	22.3	18.9	24.8	21.4
802	80-45-F	45.1	43.2	50.4	47.7	131.9	133.9	137.3	132.3	24.1	22.5	30.2	28.4
805	160-35-F	39.2	37.8	46.3	38.0	114.7	118.5	109.2	115.5	19.2	17.5	21.9	19.6
806	160-45-F	41.1	39.8	46.6	44.6	109.8	120.0	114.9	121.5	21.7	20.4	25.7	24.2
807	160-55-F	40.9	41.4	47.2	47.5	135.3	134.1	134.5	135.5	27.3	26.5	31.2	33.5
809	240-35-F	38.3	32.2	40.3	38.0	102.5	106.2	108.5	110.6	17.2	15.6	19.7	18.7
811	240-50-F	41.7	39.0	42.8	41.4	110.7	118.6	117.1	120.3	23.3	23.5	25.2	25.4
812	240-55-F	42.8	42.4	45.6	45.0	118.9	124.0	——	119.7	28.6	28.1	30.3	28.8
813	280-35-F	38.5	35.9	42.1	40.1	106.3	110.1	107.9	110.2	17.8	15.6	19.5	18.2
814	280-40-F	40.4	40.0	43.2	41.6	113.6	104.0	114.0	114.6	22.8	21.5	24.2	21.4
815	320-40-F	35.0	29.3	35.4	35.6	107.4	116.4	110.7	118.9	19.6	17.0	21.8	22.0

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Pressures from Indicator Cards											
		Pressures at Beginning of Compression, Pounds Per Square Inch								Least Back Pressure, Pounds Per Square Inch			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder			
		Right Side		Left Side		Right Side		Left Side		Right Side		Left Side	
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End
		322	323	324	325	326	327	328	329	330	331	332	333
801	80–35–F	76.4	78.7	78.7	81.2	4.8	4.3	4.4	5.3	65.1	66.4	69.3	68.0
802	80–45–F	69.2	74.2	76.8	74.3	4.4	5.4	4.6	5.8	59.2	65.5	67.5	64.9
805	160–35–F	87.0	92.6	96.8	95.4	7.6	7.4	7.6	8.3	70.3	74.3	75.7	76.5
806	160–45–F	89.9	89.3	101.2	97.3	10.3	9.6	9.0	10.8	68.4	69.9	73.7	76.4
807	160–55–F	76.9	76.7	86.6	85.2	13.0	13.1	12.5	14.3	68.0	68.0	75.7	74.7
809	240–35–F	100.9	106.5	108.7	111.5	14.8	16.5	15.4	18.7	78.0	78.6	83.9	85.1
811	240–50–F	101.4	100.8	106.4	105.2	22.3	24.2	23.8	24.8	78.4	80.9	82.0	84.2
812	240–55–F	91.3	92.2	——	98.8	27.4	26.8	27.9	27.9	81.4	81.7	——	83.4
813	280–35–F	109.1	107.8	110.4	111.4	22.2	18.8	20.0	21.4	82.3	83.8	87.9	88.8
814	280–40–F	110.0	107.0	114.4	118.6	23.4	23.5	26.8	23.2	88.6	87.2	89.0	90.2
815	320–40–F	110.4	114.0	115.3	115.3	30.3	28.1	28.3	28.2	86.2	89.4	88.4	91.7

Test Number	Laboratory Designation	Pressures from Indicator Cards				Boiler					
		Least Back Pressure, Pounds Per Square Inch				Dry Coal Fired Pounds		Evaporation, Pounds			
		Low Pressure Cylinder						Steam Per Hour			
		Right Side		Left Side							
		Head End	Crank End	Head End	Crank End	Per Hour	Per Hour Per Square Foot of Grate Surface	Moist	Dry	Dry, Per Sq. Ft. of Heating Surface	Dry Steam Per Pound of Dry Coal Fired
		334	335	336	337	338	339	340	341	342	343
801	80–35–F	1.2	1.2	1.4	2.1	1287	25.79	12466	12314	4.105	9.568
802	80–45–F	0	1.1	1.2	2.2	1749	35.05	15494	15313	5.104	8.756
805	160–35–F	1.9	1.8	2.7	3.3	2357	47.24	19965	19726	6.575	8.369
806	160–45–F	4.0	4.1	5.3	5.4	3113	62.38	25743	25422	8.474	8.167
807	160–55–F	8.3	6.9	8.6	9.6	4880	97.79	33754	32561	10.853	6.673
809	240–35–F	3.5	3.5	5.3	5.2	3024	60.61	24787	24477	8.159	8.095
811	240–50–F	9.8	9.8	11.4	10.7	5802	116.25	37046	36573	12.190	6.304
812	240–55–F	12.1	12.6	13.0	12.8	6694	134.15	41120	40034	13.343	5.980
813	280–35–F	5.1	4.2	5.9	5.2	3475	69.64	27314	26984	8.995	7.765
814	280–40–F	7.4	6.8	8.8	6.4	3889	77.94	31561	30791	10.263	7.918
815	320–40–F	6.3	5.9	7.3	7.1	4928	98.76	32906	31818	10.604	6.456

For steam lost from boiler and not delivered to engines, see item 216.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Boiler: Equiv't Evap'n from and at 212° F., Pounds: Per Hour	Boiler: Equiv't Evap'n: Per Hour, Per Sq. Ft. of Heat. Surface	Boiler: Equiv't Evap'n: Per Pound of Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Dry Coal as Fired	Boiler: Equiv't Evap'n: Per Pound of Combustible	Boiler Horse Power	Efficiency of Boiler	Engines: Mean Effective Pressure, Pounds Per Square Inch: High Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		344	345	346	347	348	349	350	351	352	353	354
801	80–35–F	15036	5.01	11.56	11.68	12.49	435.8	75.34	63.8	64.6	61.2	63.2
802	80–45–F	18703	6.23	10.59	10.69	11.48	542.2	69.00	85.3	83.4	83.1	81.2
805	160–35–F	24040	8.01	10.11	10.20	10.82	696.8	65.88	56.5	61.0	51.4	58.3
806	160–45–F	31142	10.38	9.91	10.01	10.66	902.6	64.05	73.1	79.4	73.9	73.9
807	160–55–F	39872	13.29	8.09	8.17	8.78	1155.6	53.05	97.0	95.6	90.9	90.4
809	240–35–F	29960	9.99	9.82	9.91	10.49	868.4	63.95	40.3	47.6	39.2	45.1
811	240–50–F	44765	14.92	7.65	7.72	8.28	1297.4	49.88	67.1	71.2	66.5	68.0
812	240–55–F	49025	16.34	7.25	7.32	7.77	1421.0	46.89	68.5	70.7	60.9	69.8
813	280–35–F	33055	11.02	9.42	9.51	10.27	958.1	61.81	36.4	45.8	35.3	40.4
814	280–40–F	37721	12.57	9.60	9.70	10.25	1093.3	62.11	41.2	49.7	41.5	47.1
815	320–40–F	38973	12.99	7.83	7.91	8.48	1129.6	51.02	36.6	35.0	34.8	42.6

Test Number	Laboratory Designation	Engines: Mean Effective Pressure, Pounds Per Square Inch: Low Pressure Cylinder: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End	Receiver Pressure: Right Side	Receiver Pressure: Left Side	Number of Expansions: Right Side: Head End	Right Side: Crank End	Left Side: Head End	Left Side: Crank End
		355	356	357	358	359	360	361	362	363	364
801	80–35–F	28.9	25.7	32.7	29.2			3.56	3.70	3.74	3.86
802	80–45–F	32.3	31.9	39.3	37.4			3.27	3.52	3.81	3.63
805	160–35–F	23.2	21.6	26.5	23.6			3.69	3.64	3.71	4.06
806	160–45–F	28.9	27.1	34.2	30.6			3.59	3.91	3.62	3.91
807	160–55–F	33.3	31.5	38.0	34.9			3.14	3.37	3.11	3.35
809	240–35–F	18.4	17.2	22.3	19.2			4.23	4.39	4.41	4.20
811	240–50–F	24.5	22.4	27.8	25.7			3.83	4.02	3.75	3.78
812	240–55–F	24.9	24.2	28.1	25.6			3.23	3.46	3.51	3.40
813	280–35–F	17.6	14.0	18.2	17.7			4.41	4.46	4.29	4.15
814	280–40–F	20.6	16.8	22.2	18.7			3.89	3.94	3.82	3.85
815	320–40–F	15.5	14.2	17.4	17.7			3.79	4.02	3.81	3.68

For Factor of Evaporation, see item 300.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Engines											
		Indicated Horse Power								Division of Power			
		High Pressure Cylinder				Low Pressure Cylinder				High Pressure Cylinder		Low Pressure Cylinder	
		Right Side		Left Side		Right Side		Left Side					
		Head End	Crank End	Head End	Crank End	Head End	Crank End	Head End	Crank End	Right Side	Left Side	Right Side	Left Side
		365	366	367	368	369	370	371	372	373	374	375	376
801	80–35–F	63.1	61.5	60.6	60.2	80.5	70.5	90.9	80.2	124.6	120.7	151.0	171.1
802	80–45–F	84.5	79.5	82.3	77.4	90.2	87.8	109.5	103.1	164.1	159.8	178.0	212.6
805	160–35–F	112.0	116.4	101.8	111.2	129.1	118.9	147.7	130.0	228.3	213.1	248.1	277.6
806	160–45–F	144.9	151.3	146.6	140.9	161.3	148.9	190.6	168.6	296.2	287.4	310.2	359.3
807	160–55–F	192.1	182.4	180.2	172.4	185.7	173.6	212.2	191.9	374.5	352.6	359.2	404.2
809	240–35 F	119.9	136.3	116.5	129.0	154.1	142.0	186.2	158.8	256.2	245.5	296.1	345.0
811	240–50–F	199.3	203.7	197.6	194.6	205.1	185.1	232.3	212.0	403.1	392.3	390.2	444.3
812	240–55–F	203.6	202.2	181.1	199.7	208.3	200.1	235.3	211.1	405.8	380.8	408.4	446.4
813	280–35–F	126.2	152.7	122.4	134.9	172.2	135.2	178.1	170.8	278.9	257.2	307.4	348.9
814	280–40–F	142.6	166.0	143.9	157.2	200.6	161.3	216.8	180 5	308.6	301.1	361.9	397.3
815	320–40–F	145.0	171.6	138.1	162.5	173.4	156.2	194.5	194.5	316.6	300.5	329.6	389.0

Test Number	Laboratory Designation	Engines						Locomotive			
		Division of Power			Consumed Per I. H. P., Hour			Dynamometer Horse Power	Pounds Per D. H. P., Hour		B. T. U. Per D. H. P. Hour
		Total		Total I. H. P.							
		Right Side	Left Side		Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.		Of Dry Coal	Of Dry Steam	
		377	378	379	380	381	382	383	384	385	386
801	80–35–F	275.6	291.8	567.4	2.17	20.78	32524	388.5	3.17	30.35	47501
802	80–45–F	342.1	372.4	714.4	2.34	20.47	34968	606.5	2.75	24.11	41198
805	160–35–F	476.4	490.7	967.0	2.34	19.60	35265	894.6	2.53	21.19	38119
806	160–45–F	606.4	646.7	1253.0	2.44	19·95	36823	1177.3	2.60	21.28	39194
807	160–55–F	733.7	756·8	1490.5	3.23	21.57	48051	1278.8	3.77	25.14	56013
809	240–35–F	552.3	590.5	1142.8	2.60	21.05	39897	964.0	3.08	24.96	46119
811	240–50–F	793.2	836.6	1629.8	3.52	22.18	52624	1470.1	3.90	24.59	58329
812	240–55–F	814.3	827.2	1641.4	4.04	24.14	60865	1475.6	4.49	26.86	67713
813	280–35–F	586.2	606.1	1192.3	2.87	22.27	42625	968.9	3.53	27.42	52472
814	280–40–F	670.5	698.4	1368.9	2.80	22.19	42262	1188.5	3.23	25.55	48673
815	320–40–F	646.2	689.5	1335.7	3.64	23.51	54470	1045.4	4.65	30.04	69597

For Maximum Indicated Horse Power, see item 403.

SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

New York Central and Hudson River R. R. Co.

Test Number	Laboratory Designation	Locomotive: Per One Million Foot Pounds at Draw-Bar: Dry Coal, Pounds	Dry Steam, Pounds	B. T. U.	I. H. P. Per Square Foot of: Heating Surface	Grate Surface	D. H. P. Per Square Foot of: Heating Surface	Grate Surface	Tractive Power Based on M. E. P., Pounds	Machine Friction of Locomotive, in Terms of: Horse Power	M. E. P., Pounds	Draw-Bar Pull, Pounds
		387	388	389	390	391	392	393	394	395	396	397
801	80–35–F	1.60	15.83	23997	.1891	11.37	.1295	7.79	11367	178.91		3585
802	80–45–F	1.39	12.18	20804	.2381	14.32	.2221	12.15	14281	107.97		2159
805	160–35–F	1.28	10.70	19253	.3223	19.38	.2982	17.93	9666	72.44		724
806	160–45–F	1.31	10.72	19789	.4177	25.11	.3925	23.60	12523	75.78		757
807	160–55–F	1.90	12.70	28294	.4968	29.87	.4263	25.63	14896	211.78		2116
809	240–35–F	1.56	12.61	23295	.3809	22.90	.3213	19.32	7615	178.85		1192
811	240–50–F	1.97	12.42	29467	.5433	32.66	.4900	29.46	10861	159.71		1064
812	240–55–F	2.27	13.56	34212	.5472	32.90	.4919	29.57	10935	165.88		1105
813	280–35–F	1.78	13.85	26502	.3975	23.90	.3229	19.42	6809	223.44		1276
814	280–40–F	1.63	12.91	24581	.4563	27.43	.3962	23.82	7819	180.36		1030
815	320–40–F	2.35	15.17	34219	.4452	26.77	.3485	20.95	6075	290.28		1450

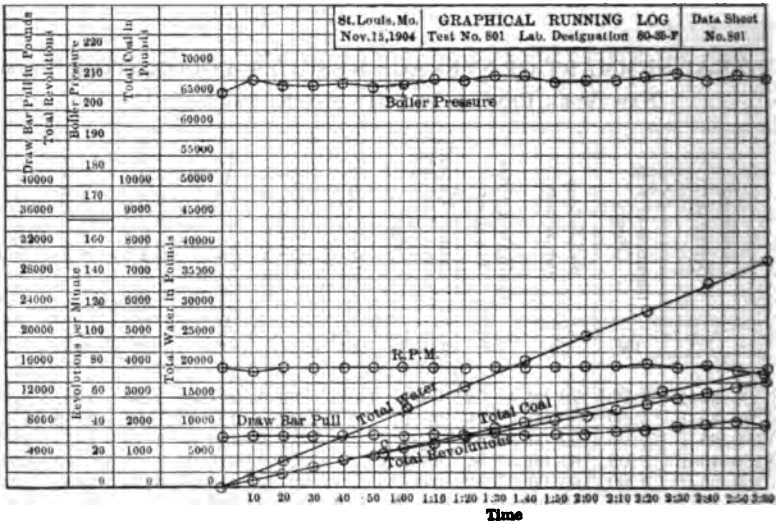
Test Number	Laboratory Designation	Locomotive: Machine Efficiency of Locomotive, Per Cent	Efficiency of Locomotive, Per Cent	Ratios: Total Weight of Locomotive to Maximum I. H. P.	Total Heating Surface to Maximum I. H. P.	Millions of Ft. Lbs. at Draw-Bar Per Hour	Maximum I. H. P.				Date of Test
		398	399	400	401	402	403	404	405	406	407
801	80–35–F	68.47	5.36	343.1	5.15	769	582.9				11–15–04
802	80–45–F	84.89	6.18	277.2	4.16	1201	721.6				11–16–04
805	160–35–F	92.51	6.67	197.4	2.96	1771	1013.3				11–17–04
806	160–45–F	93.95	6.49	156.1	2.34	2331	1280.8				11–21–04
807	160–55–F	85.80	4.55	131.6	1.97	2532	1519.8				11–23–04
809	240–35–F	84.35	5.52	172.6	2.59	1908	1158.9				11–21–04
811	240–50–F	90.20	4.36	118.5	1.78	2911	1688.4				11–22–04
812	240–55–F	89.90	4.01	117.9	1.77	2922	1696.6				11–24–04
813	280–35–F	81.25	4.85	165.6	2.48	1918	1207.5				11–22–04
814	280–40–F	86.83	5.23	141.2	2.12	2358	1416.8				11–24–04
815	320–40–F	78.27	3.42	143.7	2.16	2070	1391.5				11–24–04

GENERAL SUMMARY OF AVERAGE RESULTS—LOCOMOTIVE No. 3000.

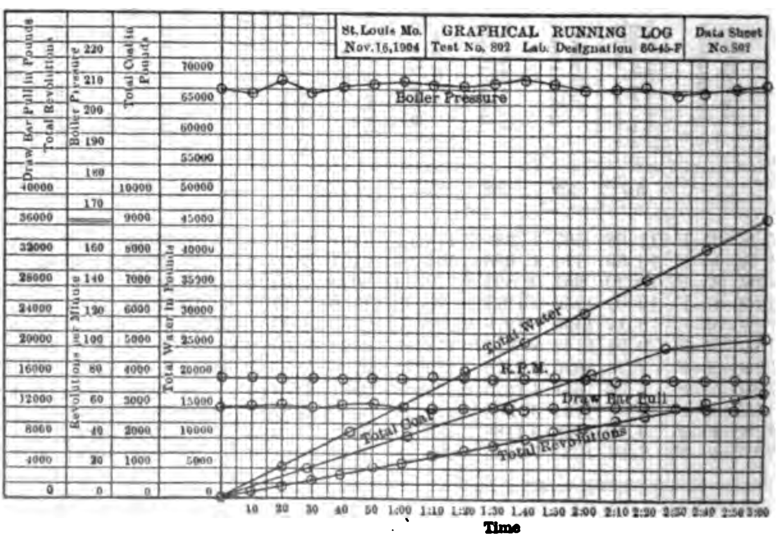
NEW YORK CENTRAL AND HUDSON RIVER R. R. CO.

Test Number	Laboratory Designation	Duration of Test, Hours	Revolutions Per Minute	Equivalent Miles Per Hour	Approximate Cut-Off, Per Cent of Stroke, High Pressure Cylinder	Position of Throttle	Boiler Pressure, Pounds Per Square Inch	Branch Pipe Pressure, Pounds Per Square Inch	Draft, Front of Diaphragm, Inches of Water	Dry Coal Fired Per Hour, Pounds	Dry Steam Used Per Hour, Pounds
		196	198	199	268 to 271	203	217	220	222	338	341
801	80–35–F	3.00	79.82	18.72	36.0	FULL	209.4	207.0	1.40	1287	12314
802	80–45–F	3.00	80.00	18.76	45.9	"	210.8	207.9	1.95	1749	15313
805	160–35–F	3.00	160.00	37.52	36.3	"	222.2	218.6	2.79	2357	19726
806	160–45–F	3.00	160.00	37.52	43.7	"	220.4	216.0	4.17	3113	25422
807	160–55–F	3.00	160.00	37.52	57.1	"	221.4	216.3	6.29	4880	32561
809	240–35–F	2.00	240.00	56.29	32.2	"	218.7	214.6	4.06	3024	24477
811	240–50–F	2.00	239.99	56.28	46.6	"	219.6	212.8	7.41	5802	36573
812	240–55–F	1.76	240.00	56.29	53.7	"	212.3	205.2	8.86	6694	40034
813	280–35–F	1.50	280.11	65.69	32.2	"	220.0	215.6	4.77	3475	26984
814	280–40–F	1.00	279.97	65.66	38.2	"	220.2	214.1	6.51	3889	30791
815	320–40–F	1.00	320.00	75.05	41.0	"	222.3	215.8	6.08	4928	31818

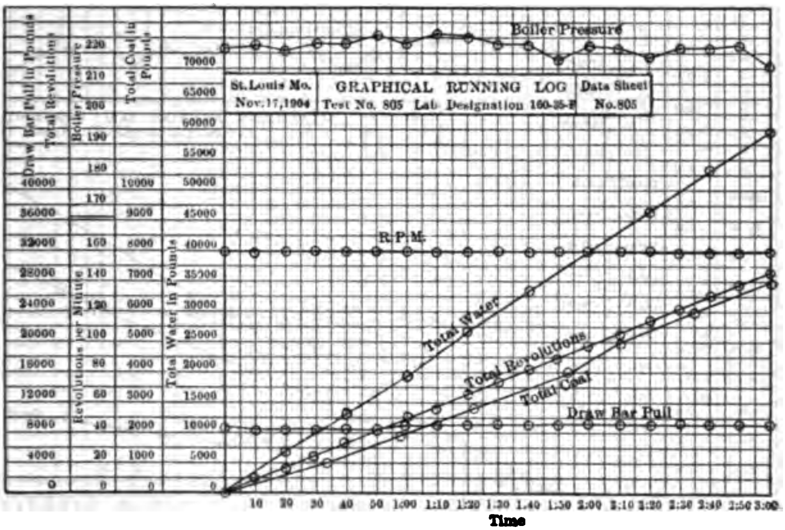
Test Number	Laboratory Designation	Equivalent Pounds Water Per Pound Coal From and at 212° F.	Indicated Horse Power	Dynamometer Horse Power	Frictional Horse Power	Draw-Bar Pull, Pounds	Dry Coal Per I. H. P. Hour, Pounds	Dry Coal Per D. H. P. Hour, Pounds	Dry Steam Per I. H. P. Hour, Pounds	Dry Steam Per D. H. P. Hour, Pounds	Efficiency of Boiler	Efficiency of Locomotive
		317	379	383	395	265	380	384	381	385	350	399
801	80–35–F	11.68	567.4	388.5	178.91	7781	2.17	3.17	20.78	30.85	75.84	5.36
802	80–45–F	10.69	714.4	606.5	107.97	12121	2.34	2.75	20.47	24.11	69.00	6.18
805	160–35–F	10.20	967.0	894.6	72.44	8940	2.34	2.53	19.60	21.19	65.88	6.67
806	160–45–F	10.01	1258.0	1177.3	75.73	11766	2.44	2.60	19.95	21.23	64.05	6.49
807	160–55–F	8.17	1490.5	1278.8	211.73	12780	3.23	3.77	21.57	25.14	53.05	4.55
809	240–35–F	9.91	1142.8	964.0	178.85	6422	2.60	3.08	21.05	24.96	63.95	5.52
811	240–50–F	7.72	1629.8	1470.1	159.71	9796	3.52	3.90	22.18	24.59	49.83	4.36
812	240–55–F	7.32	1641.4	1475.6	165.88	9831	4.04	4.49	24.14	26.86	46.89	4.01
813	280–35–F	9.51	1192.3	968.9	228.44	5530	2.87	3.58	22.27	27.42	61.81	4.85
814	280–40–F	9.70	1368.9	1188.5	180.36	6788	2.80	3.23	22.19	25.55	62.11	5.23
815	320–40–F	7.91	1335.7	1045.4	290.28	5224	3.64	4.65	23.51	30.04	51.02	3.42



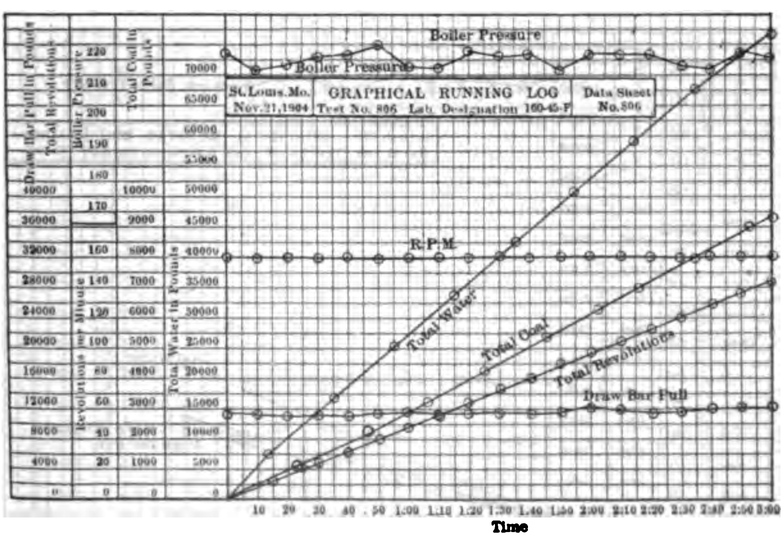
Test No. 801.



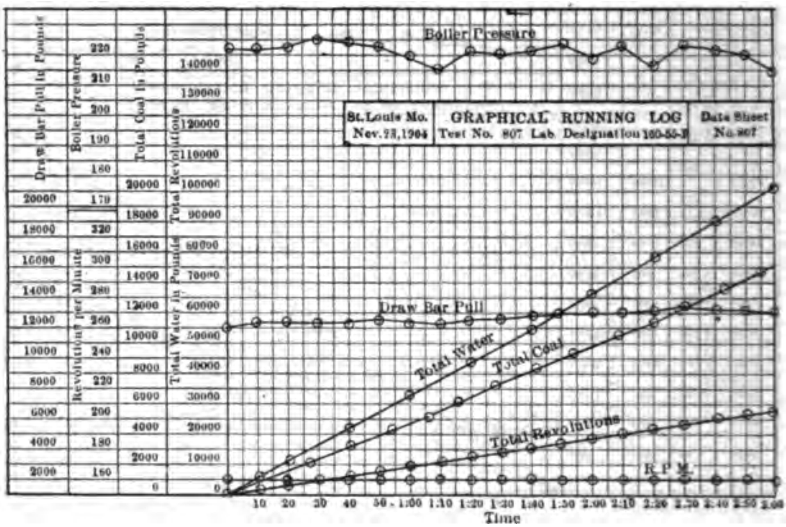
Test No. 802.



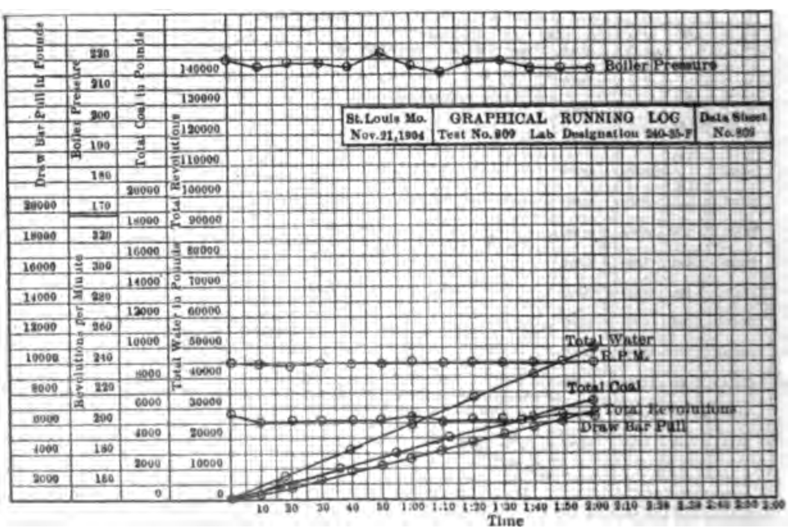
Test No. 805.



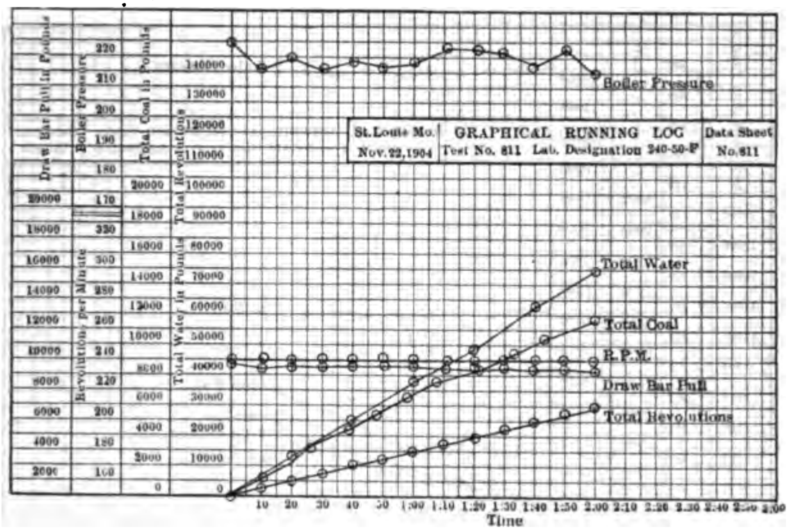
Test No. 806.



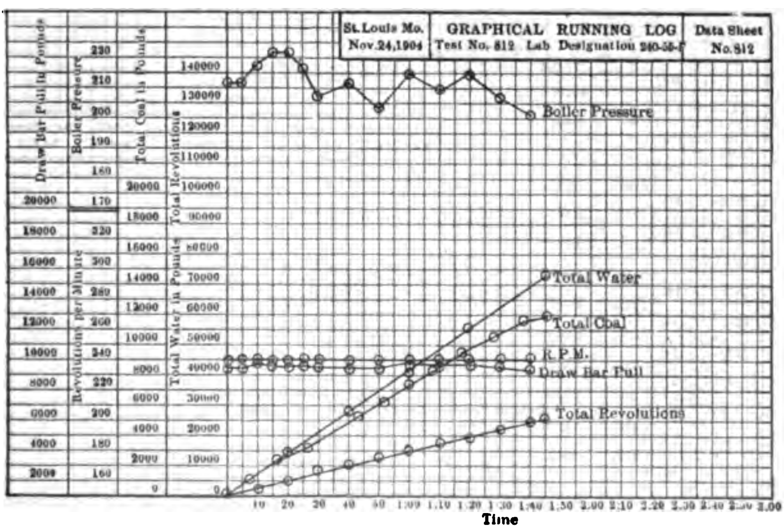
Test No. 807.



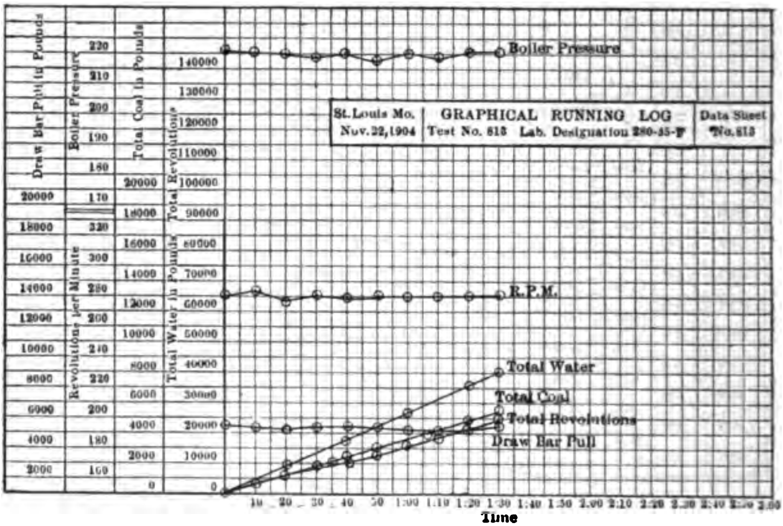
Test No. 809.



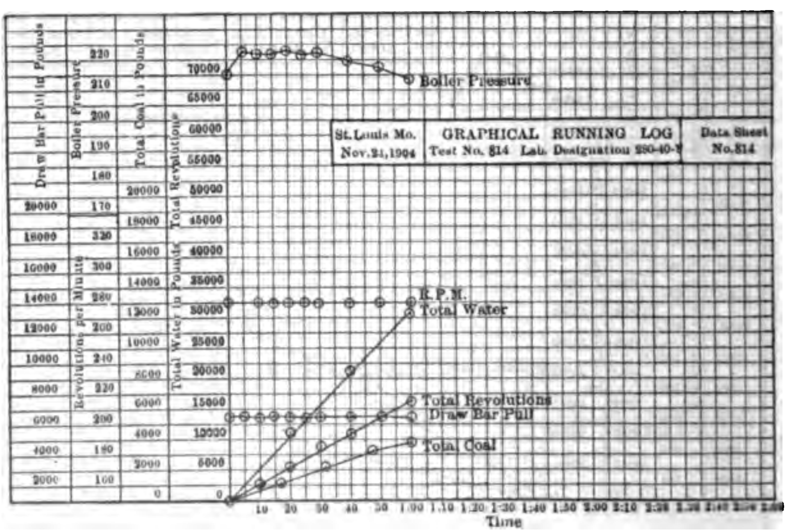
Test No. 811.



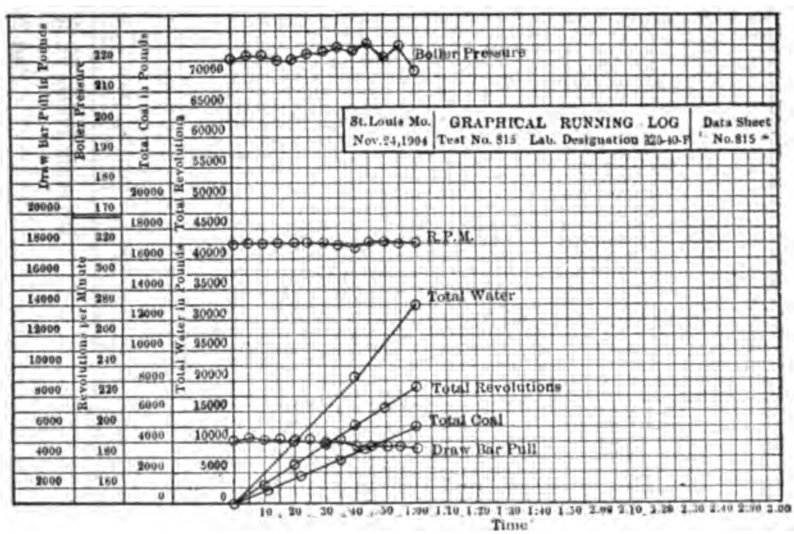
Test No. 812.



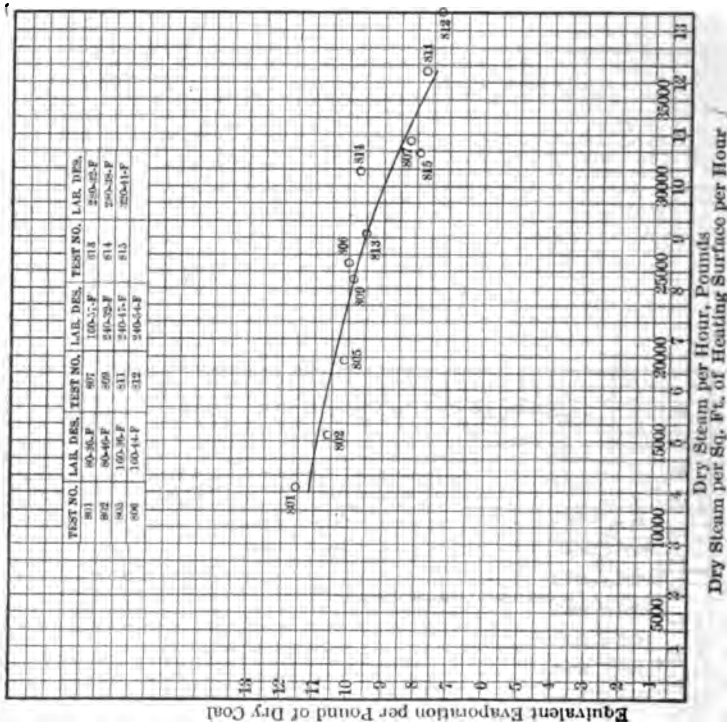
Test No. 813.



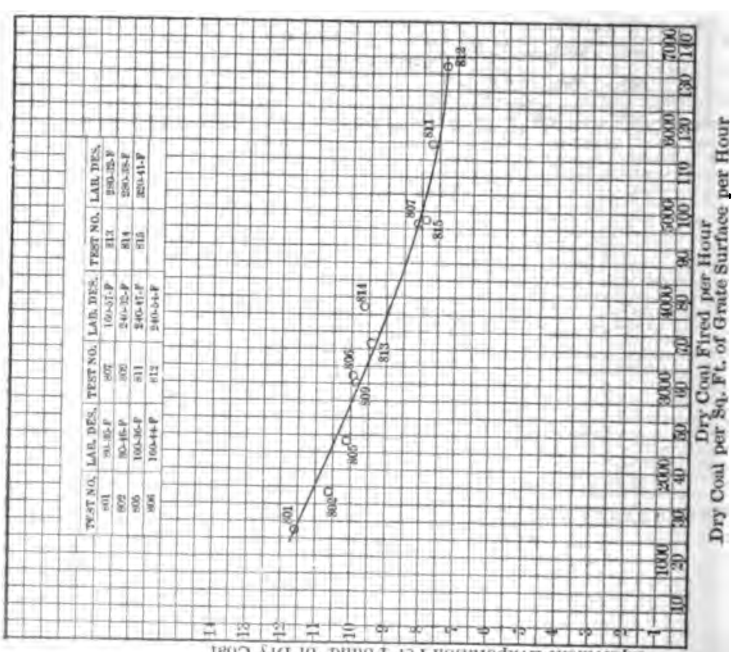
Test No. 814.


Boiler Pressure
St. Louis Mo. Nov. 24, 1904
GRAPHICAL RUNNING LOG
Test No. 815 Lab. Designation 320-40-F
Data Sheet No. 815
R.P.M.
Total Water
Total Revolutions
Total Coal
Draw Bar Pull
Draw Bar Pull in Pounds
Boiler Pressure
Revolutions per Minute
Total Coal in Pounds
Total Water in Pounds Total Revolutions
Time

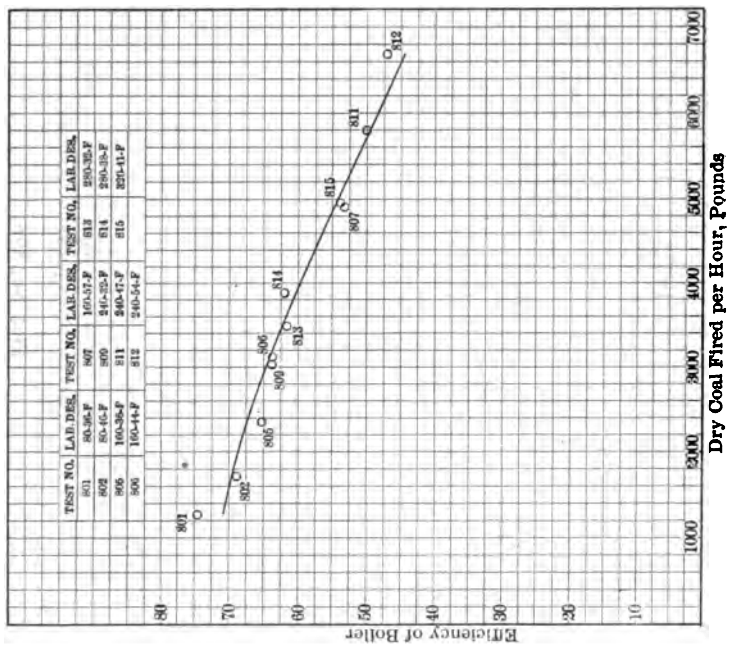
Test No. 815.



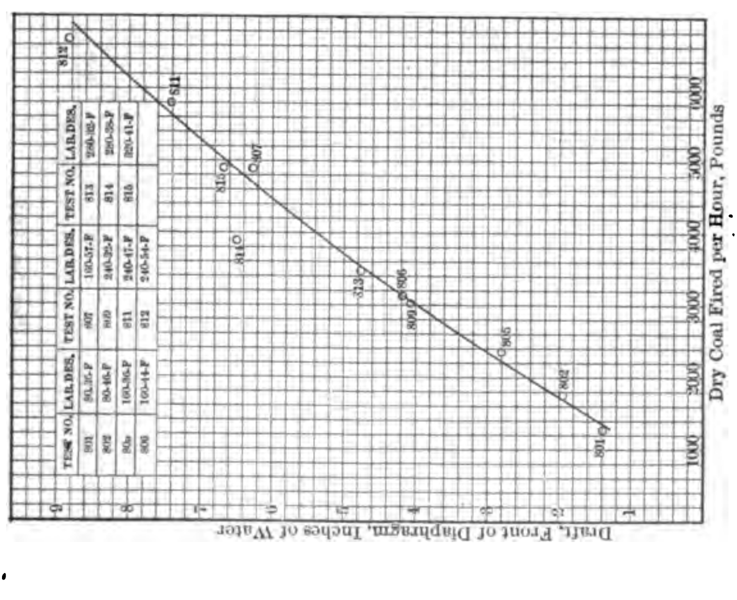
Plot No. 802.



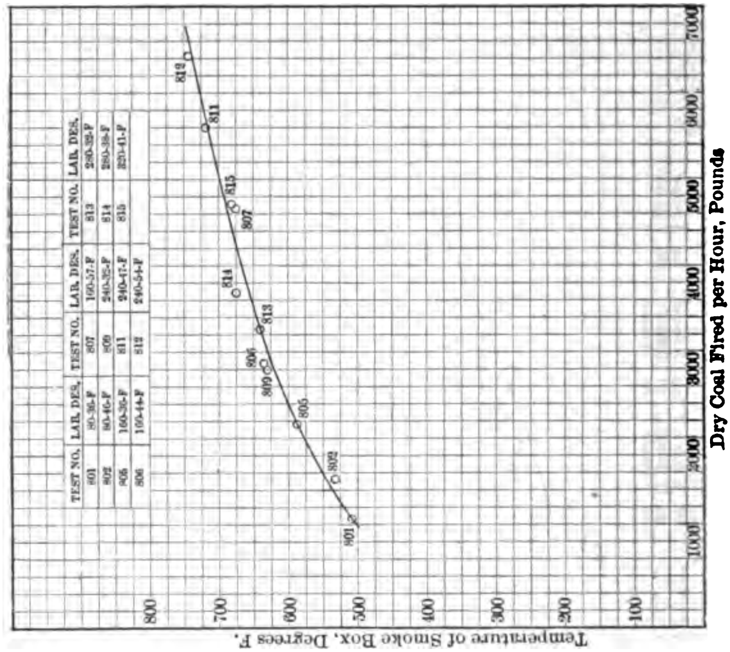
Plot No. 801.



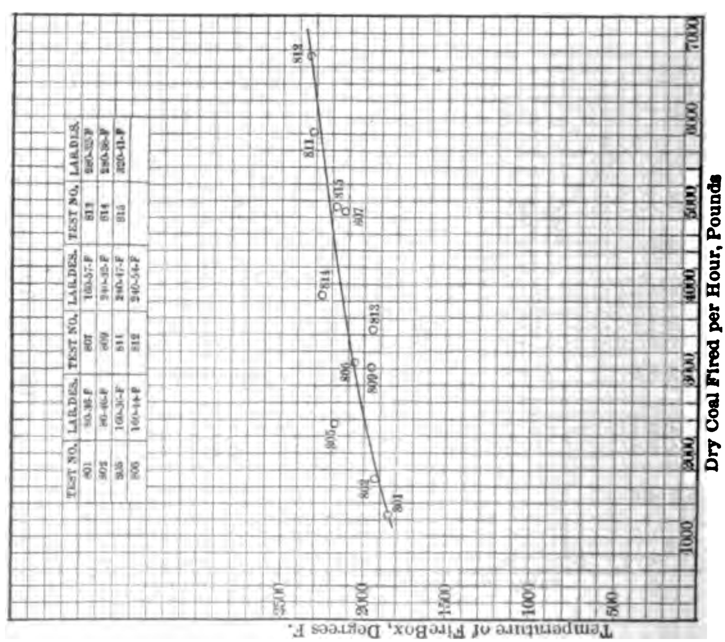
Plot No. 804.



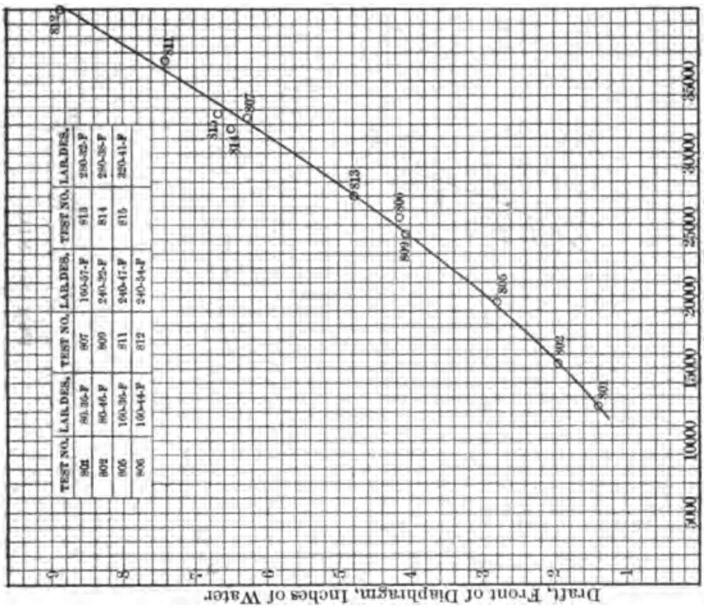
Plot No. 803.



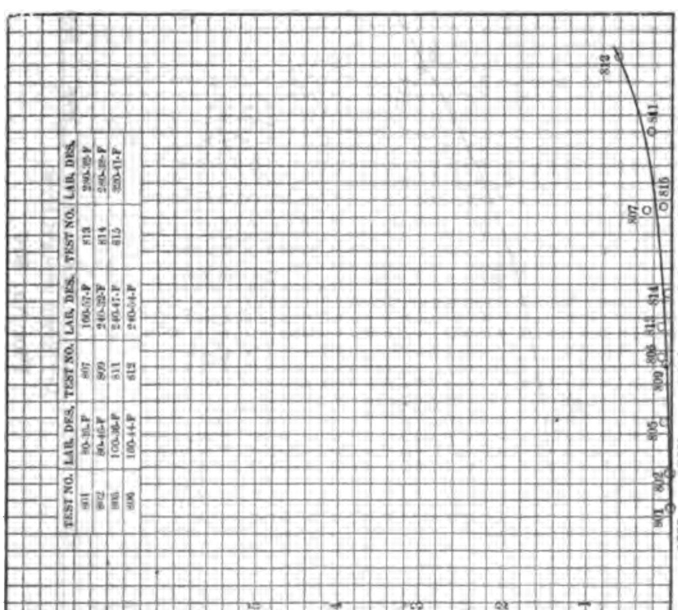
Plot No. 806.



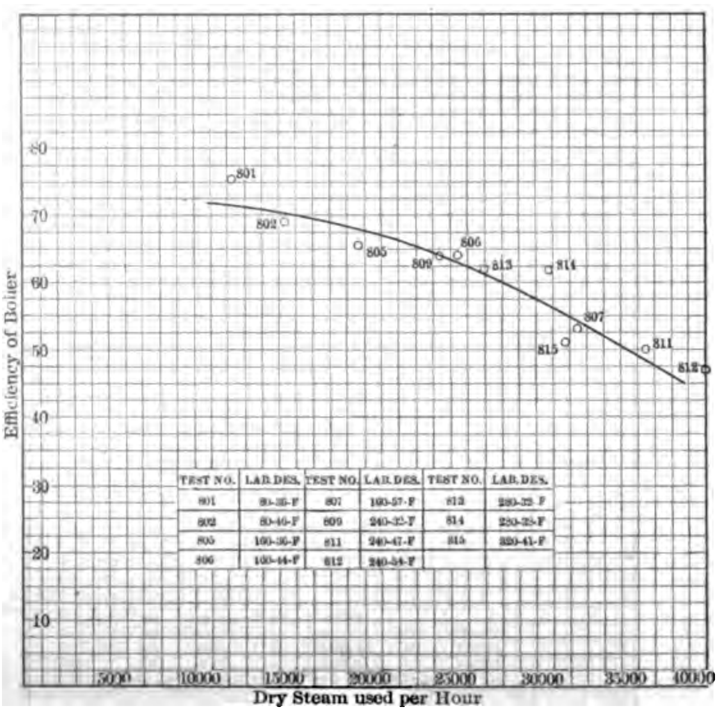
Plot No. 805.



Plot No. 808.

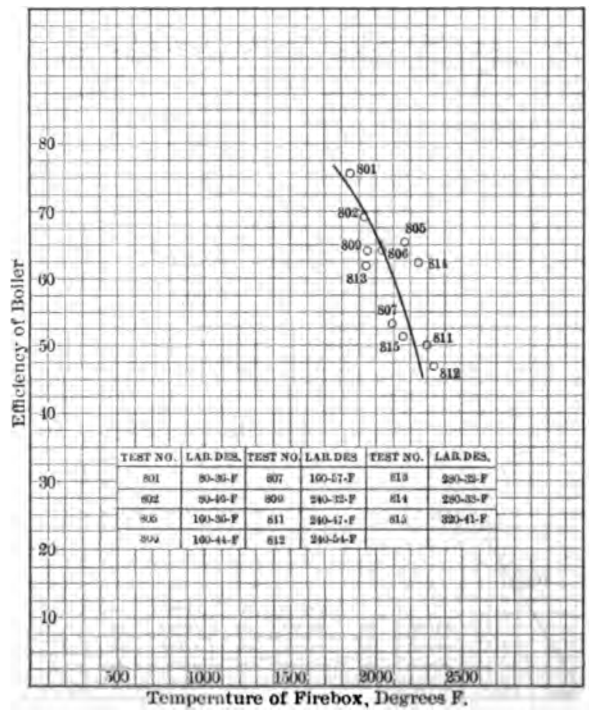


Plot No. 807.



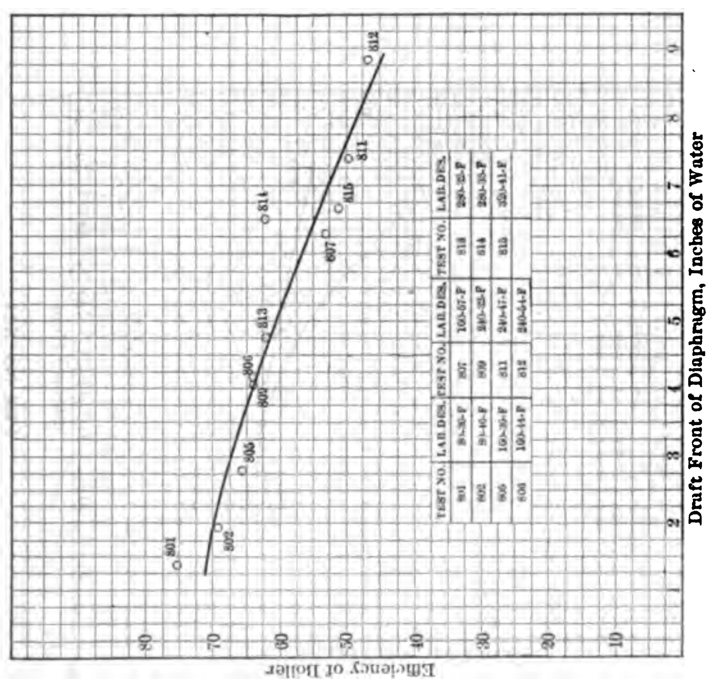
TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
801	80-35-F	807	160-57-F	813	280-32-F
802	80-46-F	809	240-32-F	814	280-33-F
805	160-36-F	811	240-47-F	815	320-41-F
806	160-44-F	812	240-54-F		

Plot No. 809.

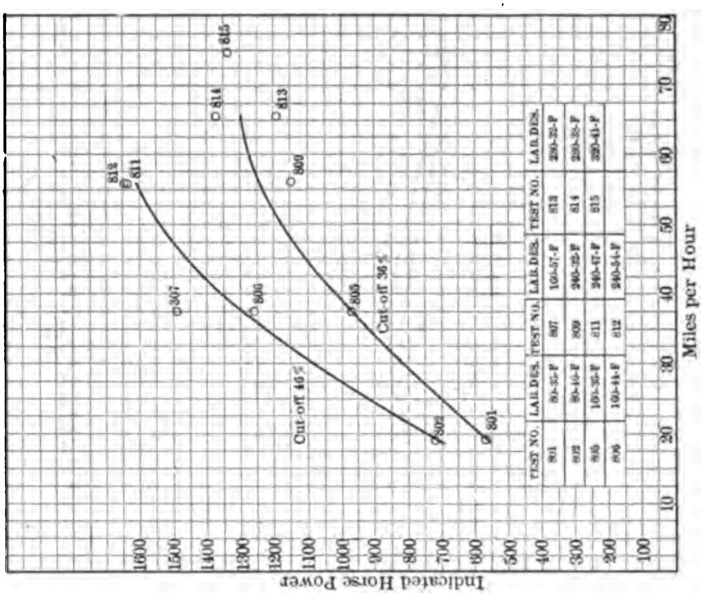


TEST NO.	LAB. DES.	TEST NO.	LAB. DES.	TEST NO.	LAB. DES.
801	80-35-F	807	160-57-F	813	280-32-F
802	80-46-F	809	240-32-F	814	280-33-F
805	160-36-F	811	240-47-F	815	320-41-F
806	160-44-F	812	240-54-F		

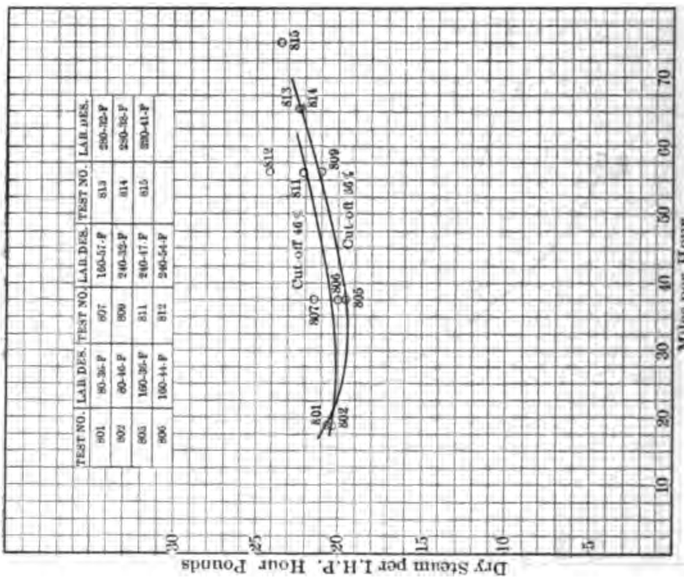
Plot No. 810.



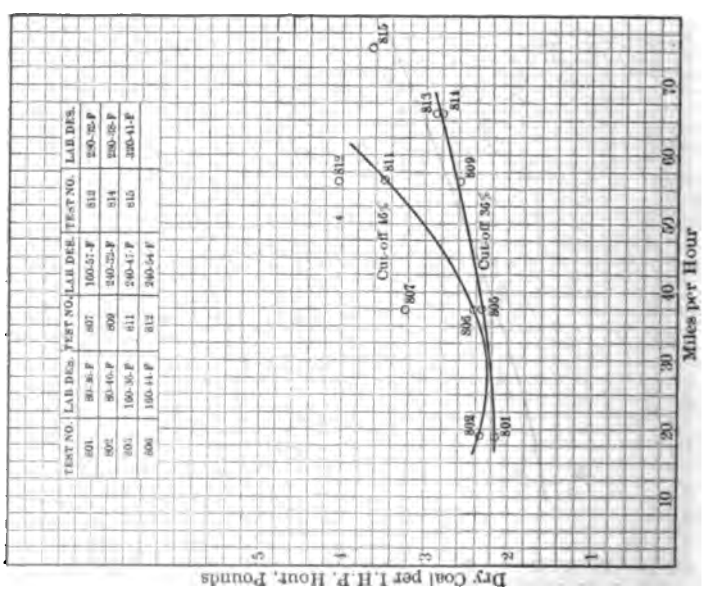
Plot No. 811.



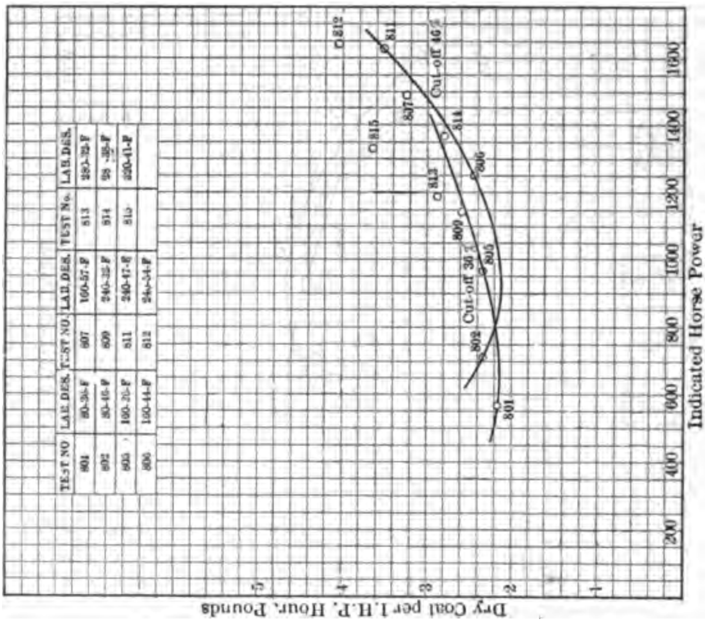
Plot No. 820.



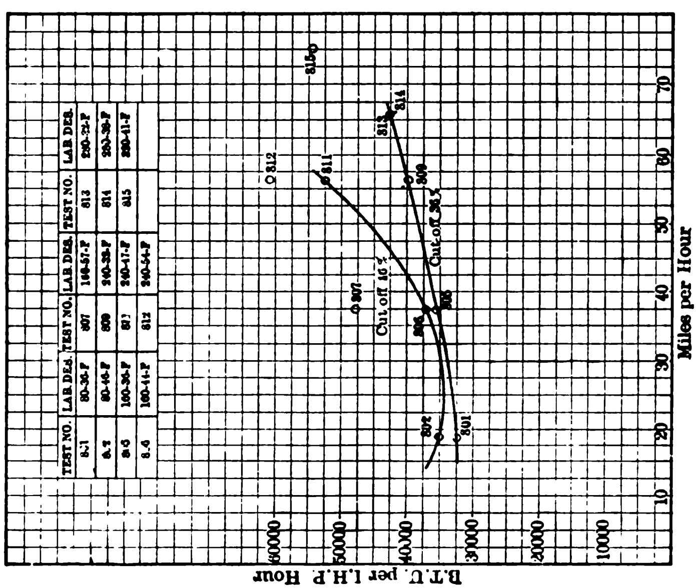
Plot No. 822.



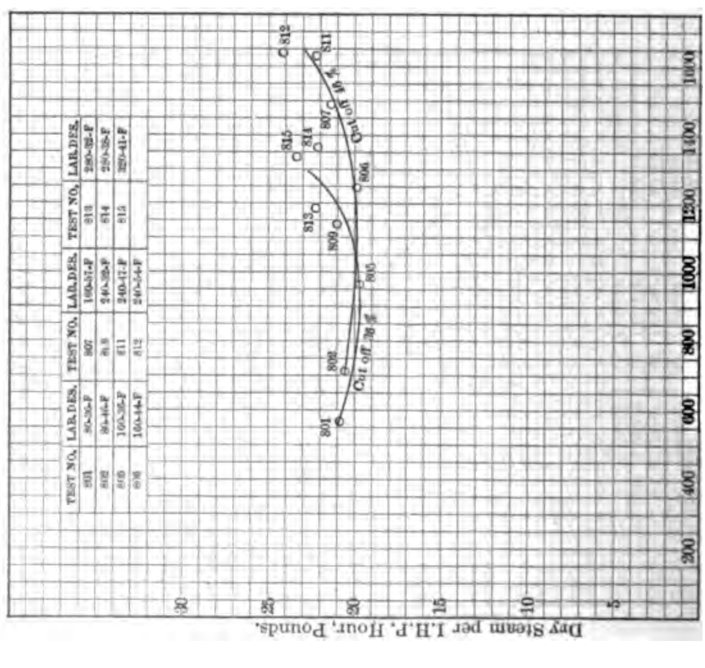
Plot No. 821.



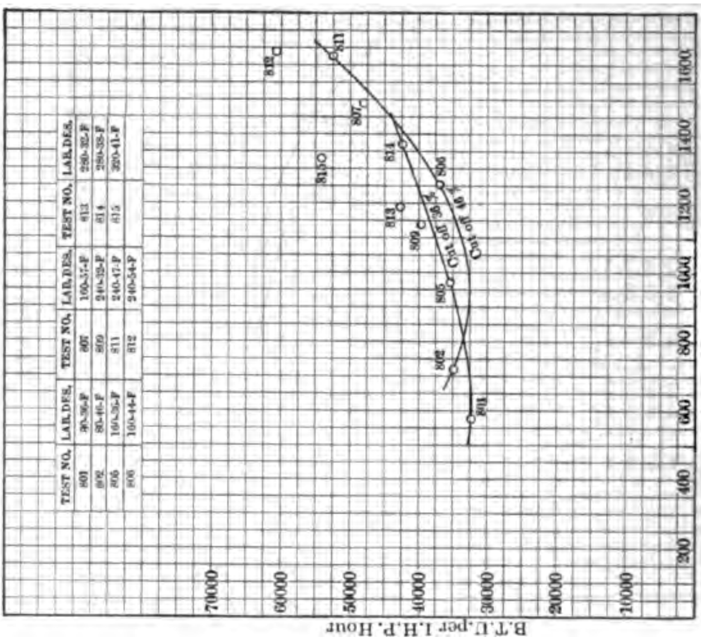
Plot No. 824.



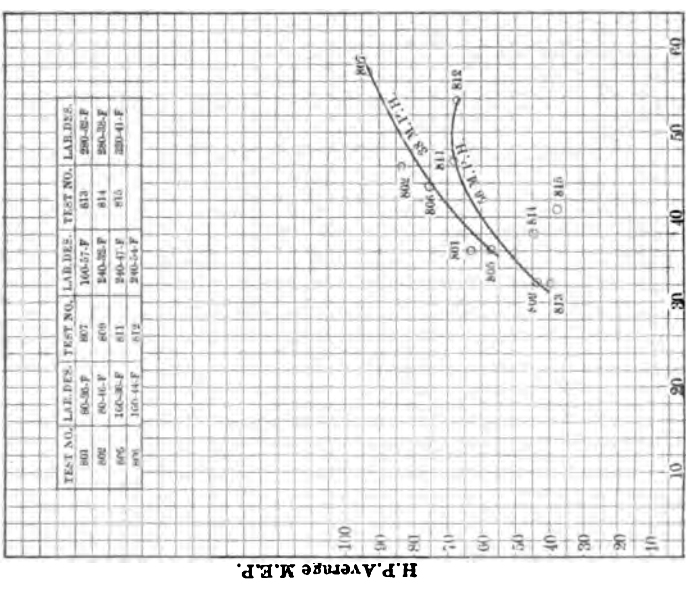
Plot No. 823.



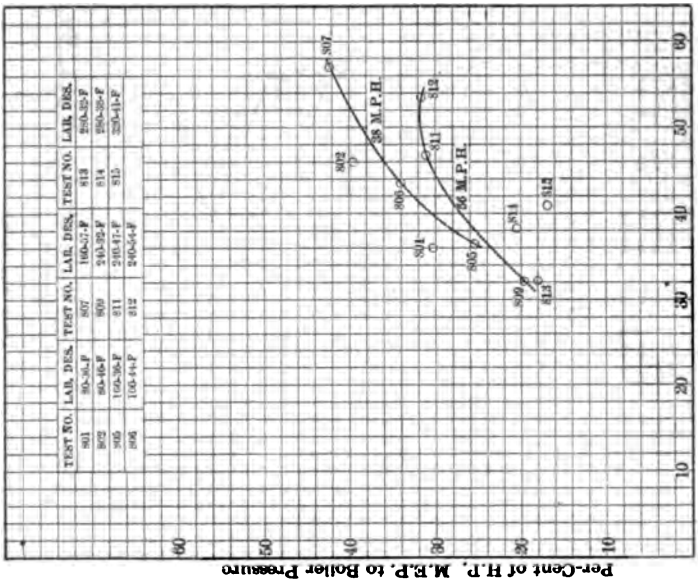
Plot No. 825.



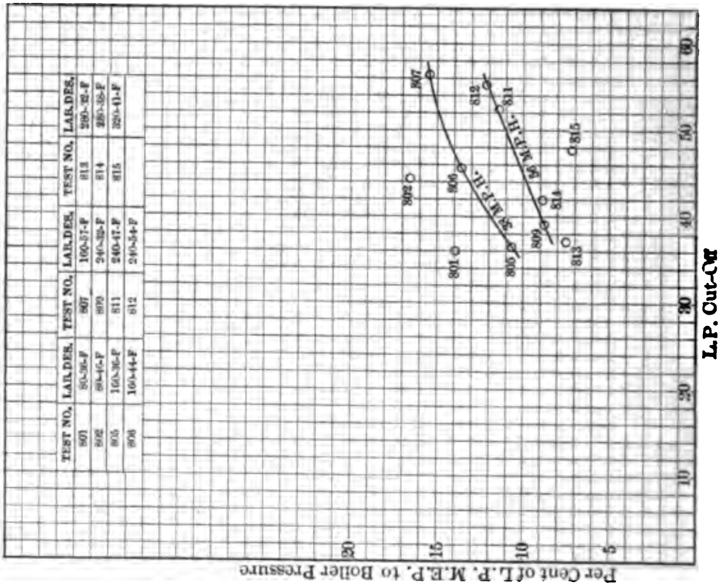
Plot No. 826.



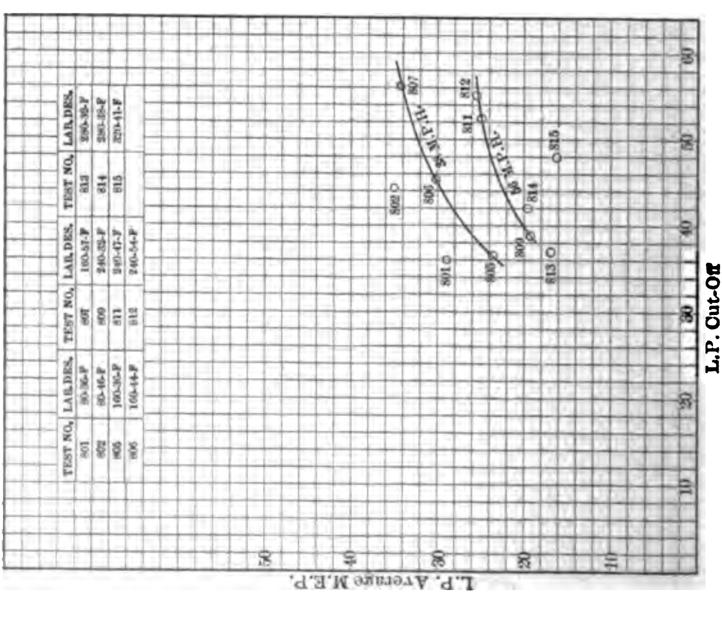
Plot No. 827.



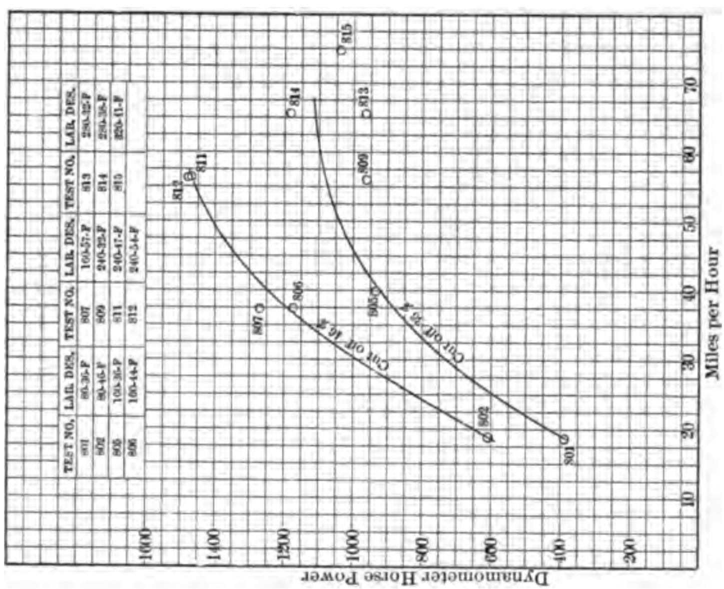
Plot No. 828.



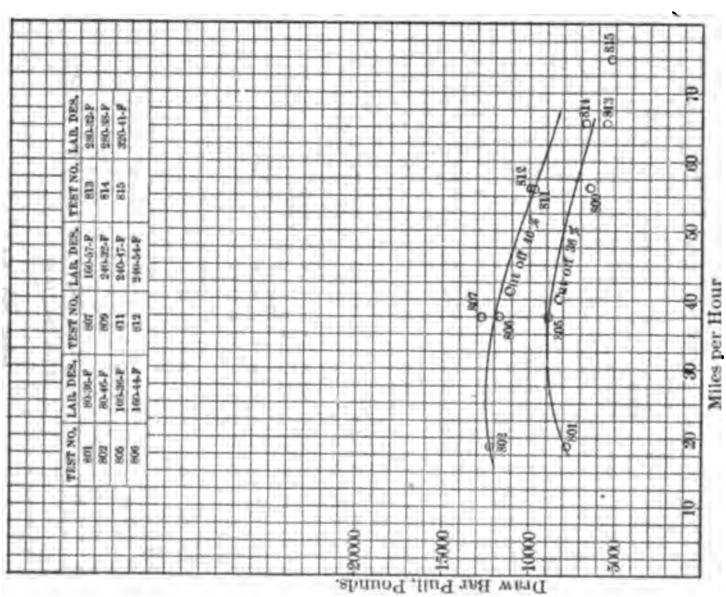
Plot No. 830.



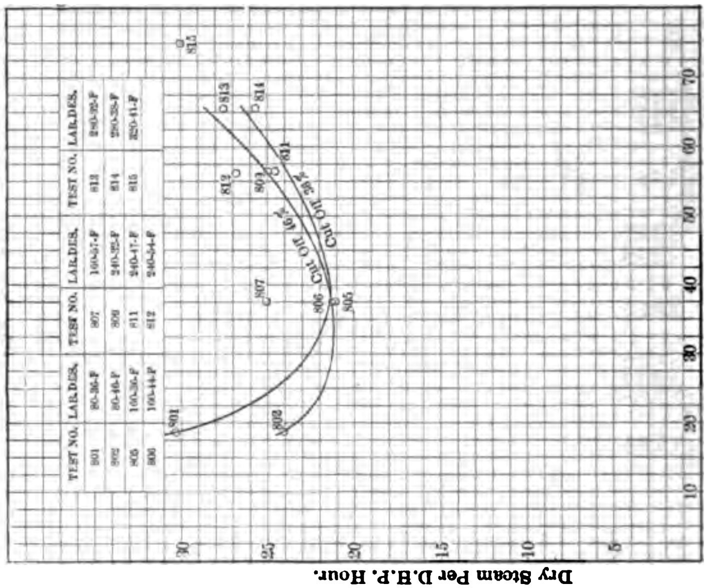
Plot No. 829.



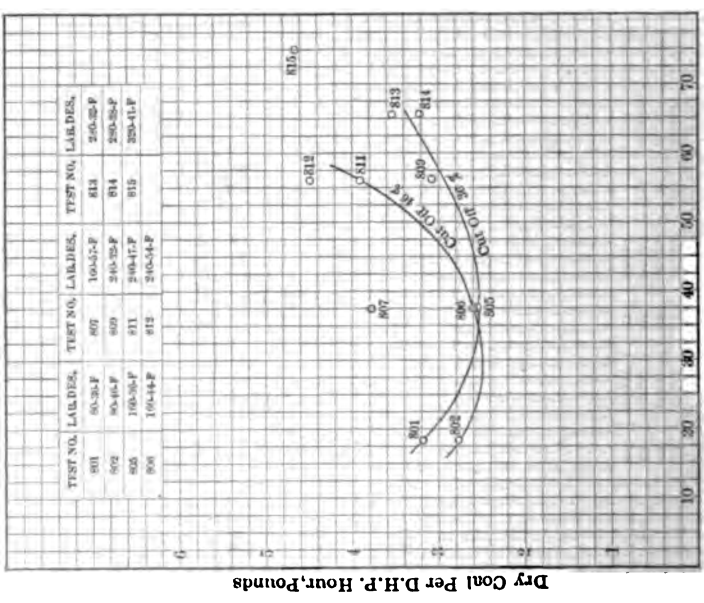
Plot No. 841.



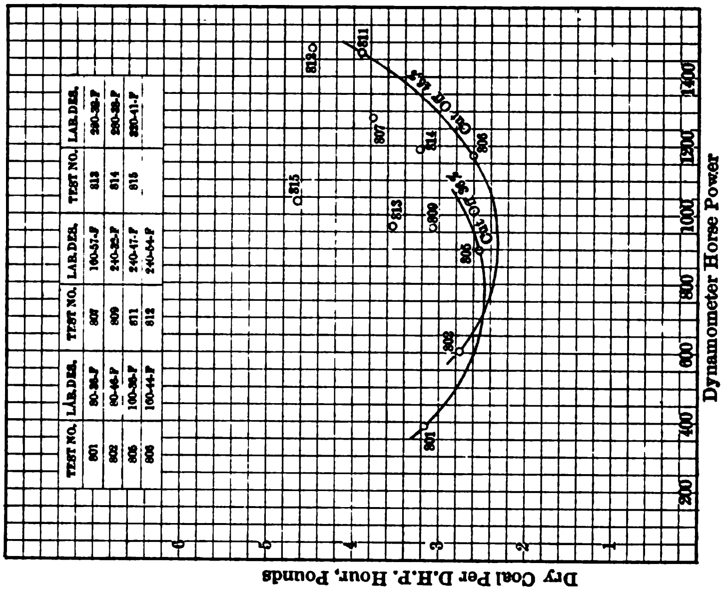
Plot No. 840.



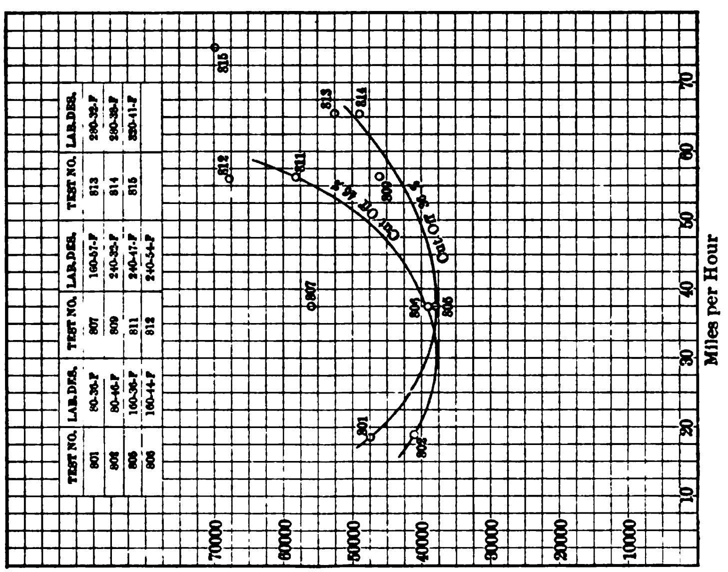
Plot No. 843.



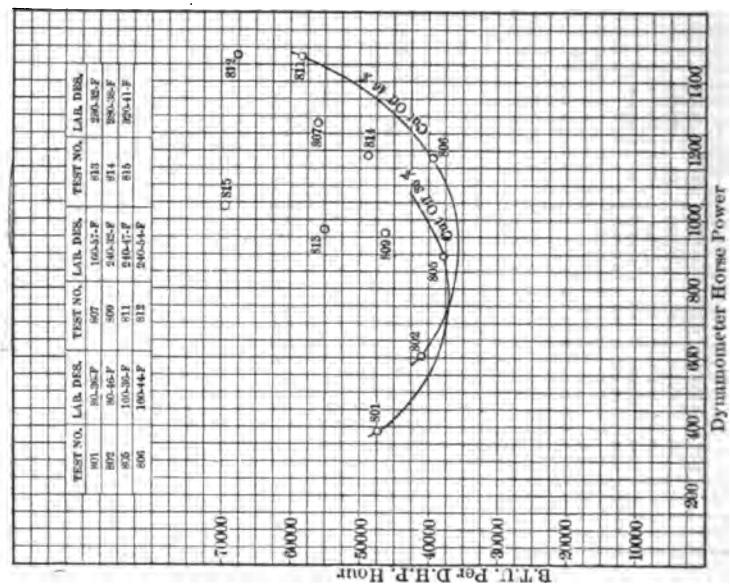
Plot No. 842.



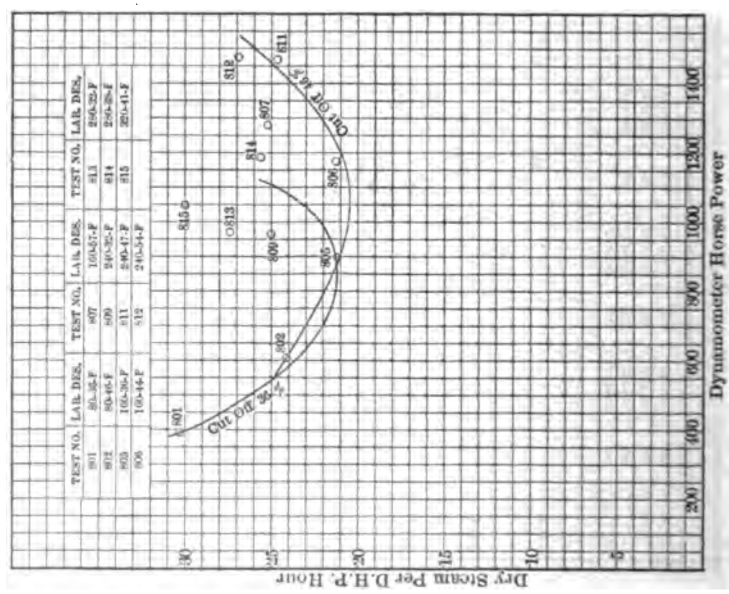
Plot No. 845.



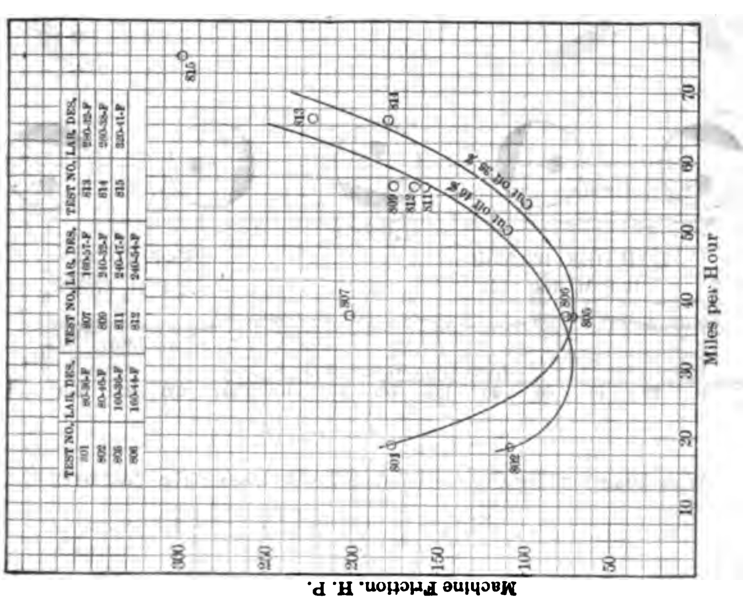
Plot No. 844.



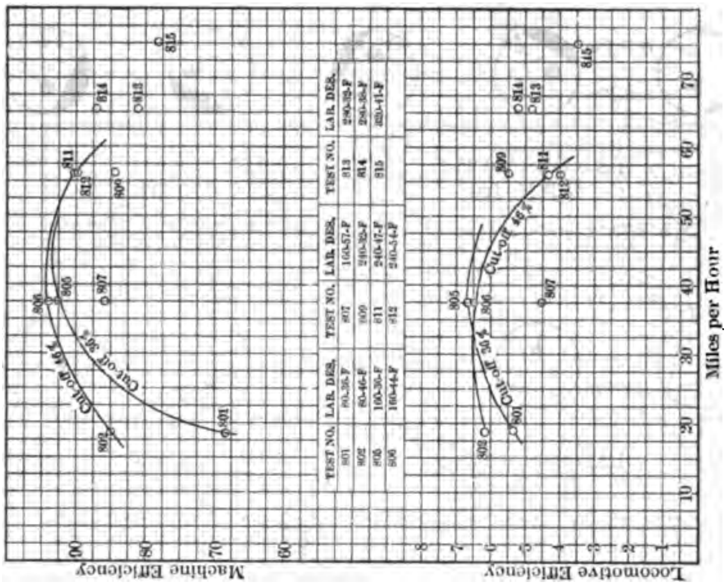
Plot No. 847.



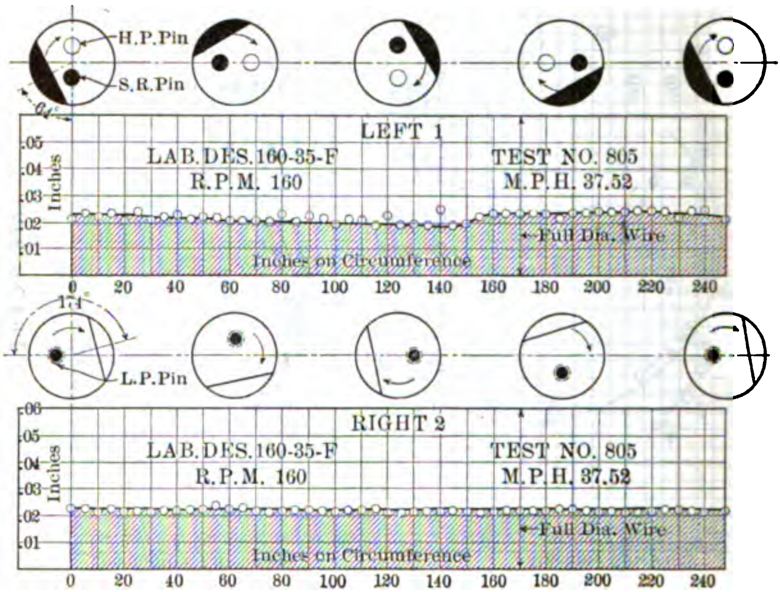
Plot No. 846.

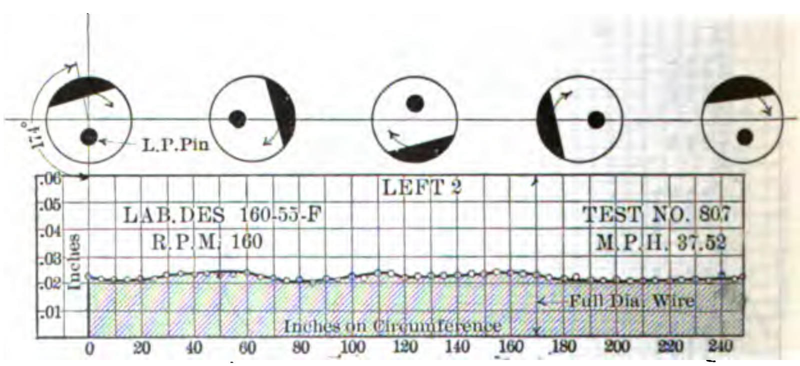


Plot No. 848.



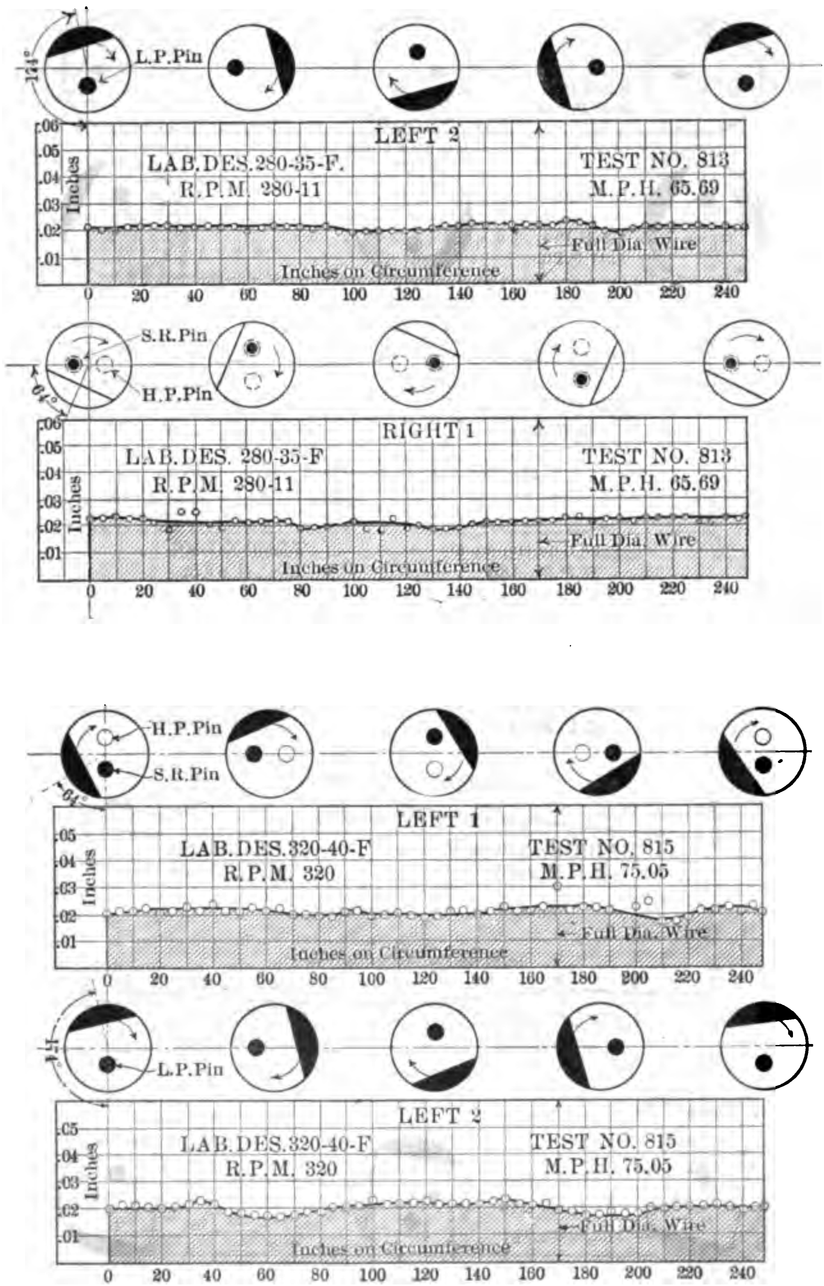
Plot No. 849.



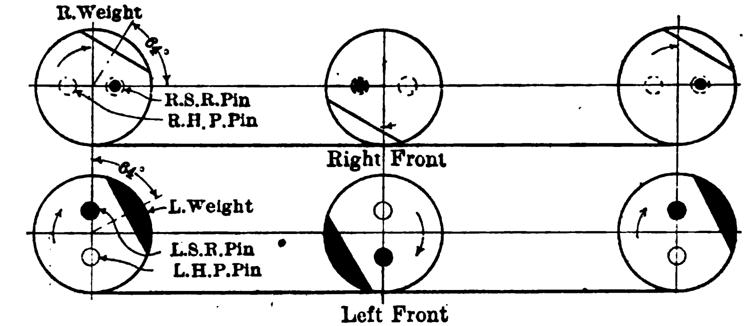


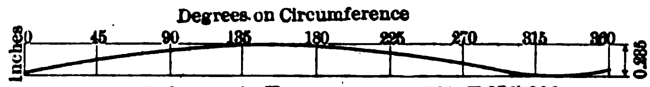
Wire Diagrams for Counterbalance Tests, Locomotive No. 3000.

For explanation see page 451.

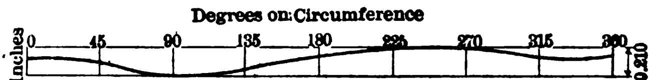


Wire Diagrams for Counterbalance Tests, Locomotive No. 3000.

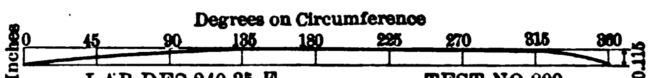




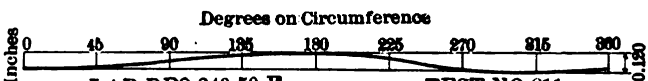
LAB.DES.160-45-F. TEST NO.806
R.P.M.160 M.P.H.37.52



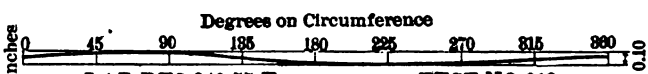
LAB.DES.160-55-F TEST NO.807
R.P.M. 160 M.P.H.37.52



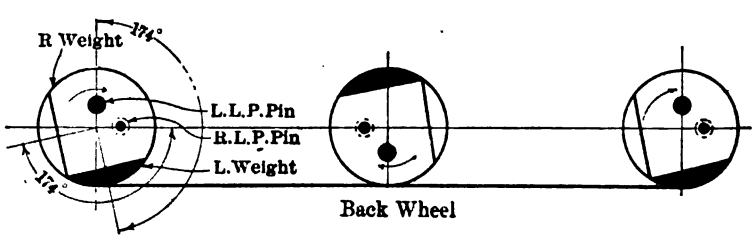
LAB.DES.240-35-F. TEST NO.809
R.P.M.240 M.P.H.56.29



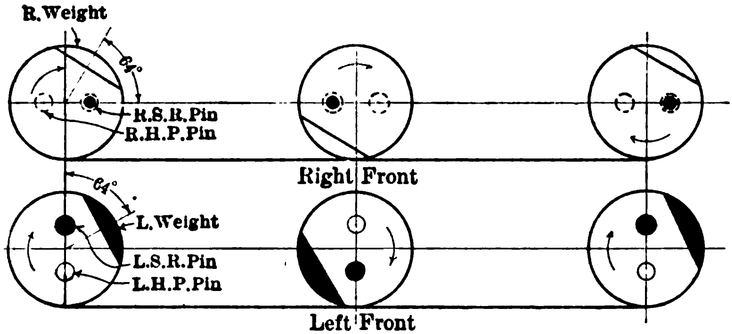
LAB.DES.240-50-F. TEST NO.811
R.P.M.239.99 M.P.H.56.28

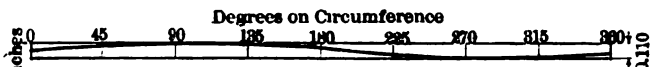


LAB.DES.240-55-F. TEST NO.812
R.P.M.240 M.P.H.56.29



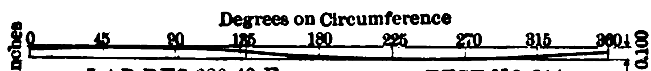
Nosing Diagrams, Locomotive No. 3000,





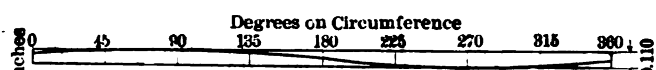
LAB.DES.280-35-F. TEST NO.813

R.P.M.280.11 M.P.H.65.69



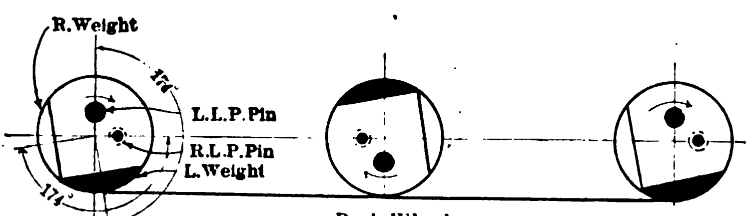
LAB.DES.280-40-F TEST NO.814

R.P.M.279.97 M.P.H.65.66

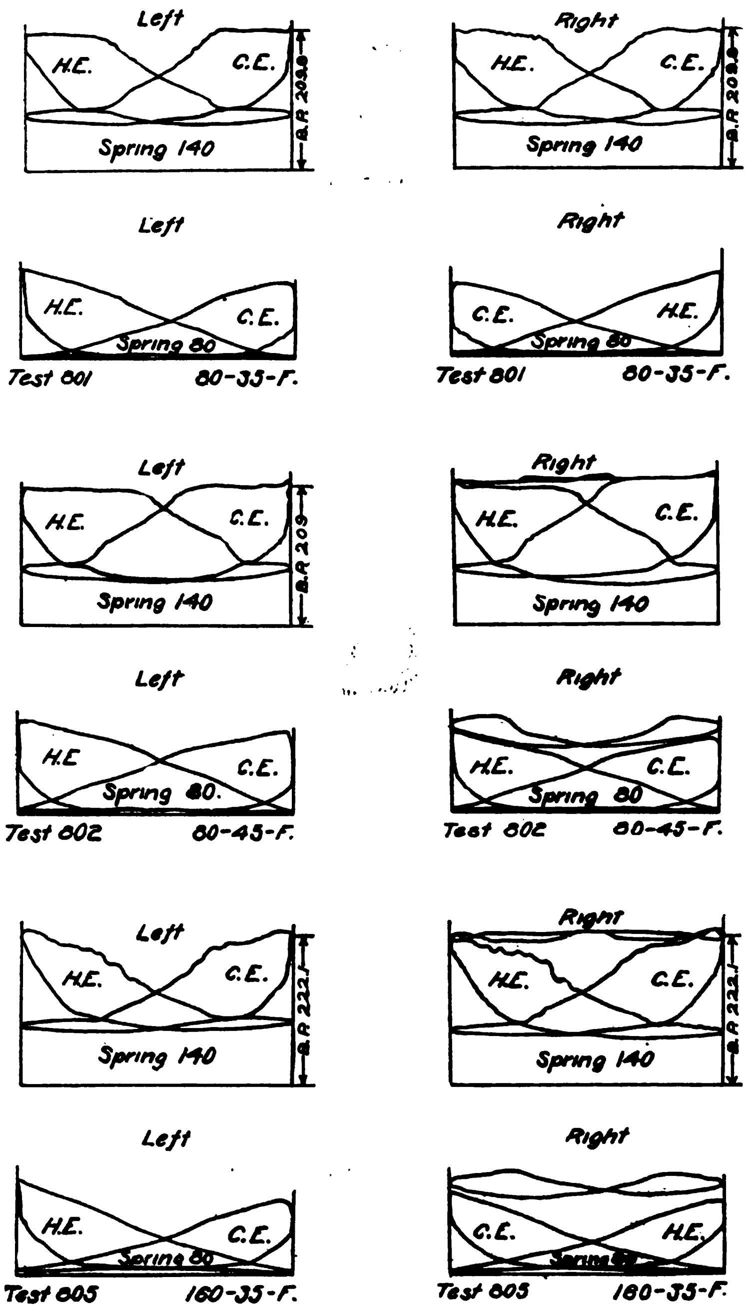


LAB.DES.320 40-F. TEST NO.815

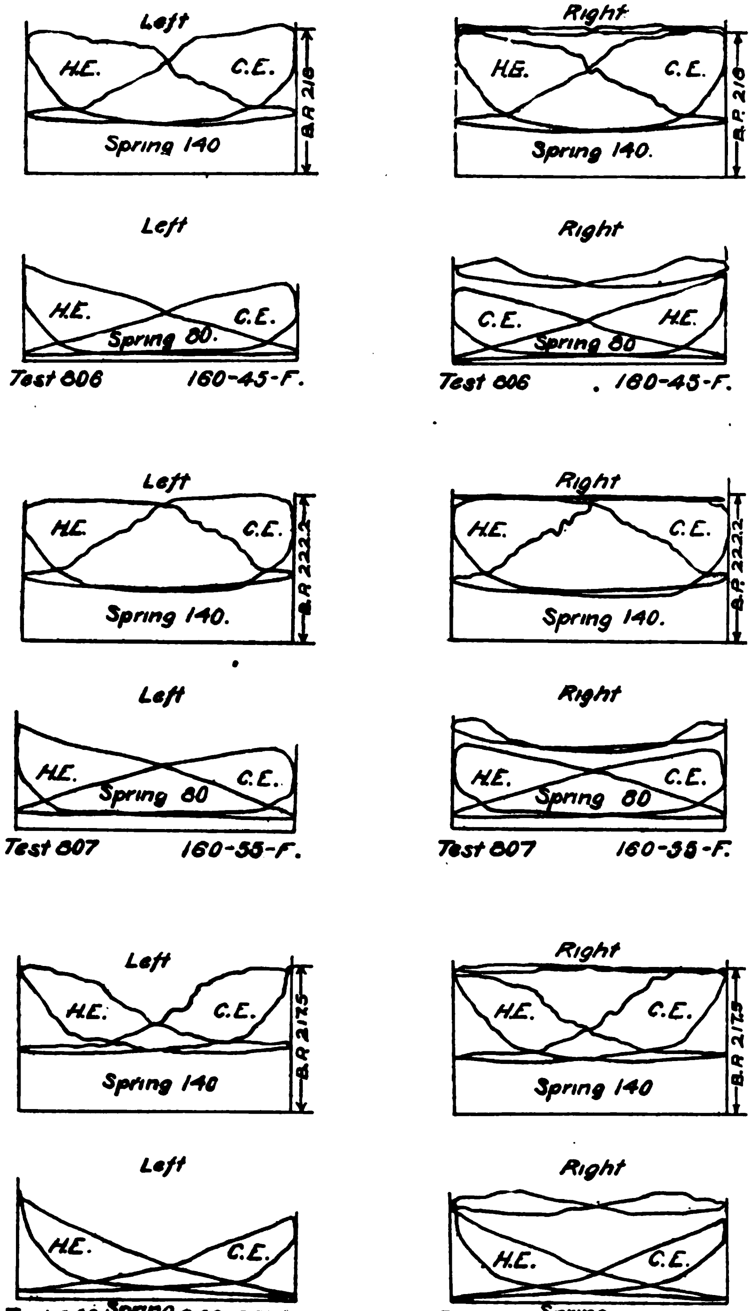
R.P.M.320 M.P.H.75.05



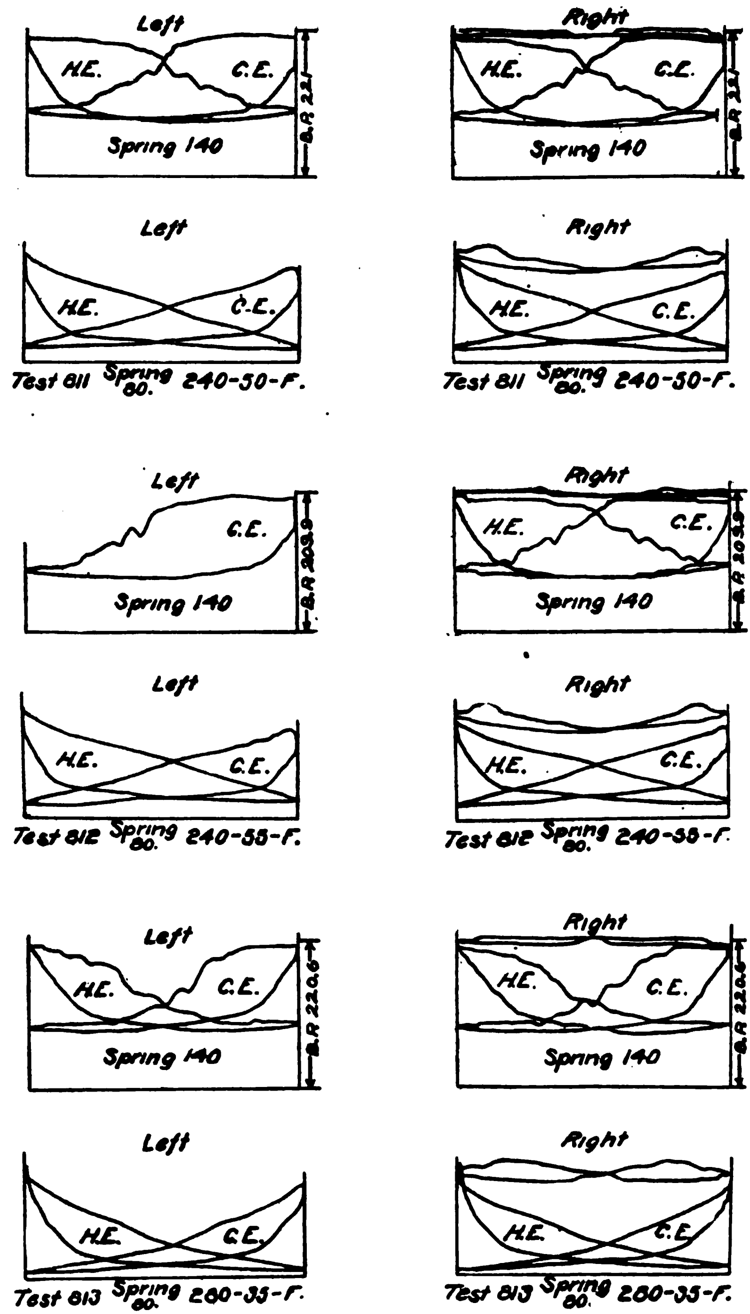
Nosing Diagrams, Locomotive No, 3000.



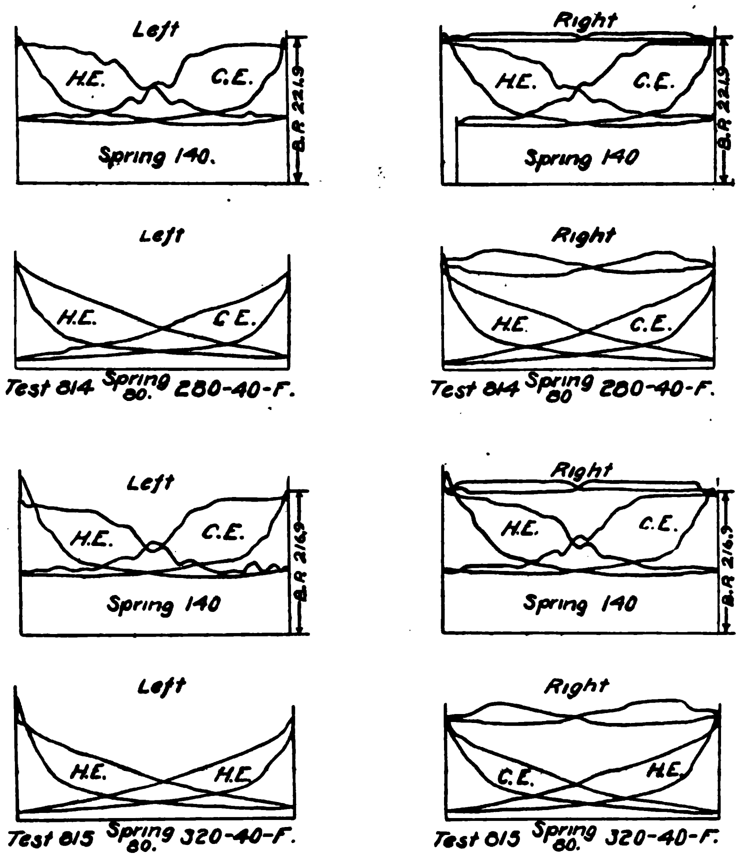
Typical Indicator Diagrams, Locomotive No. 3000.



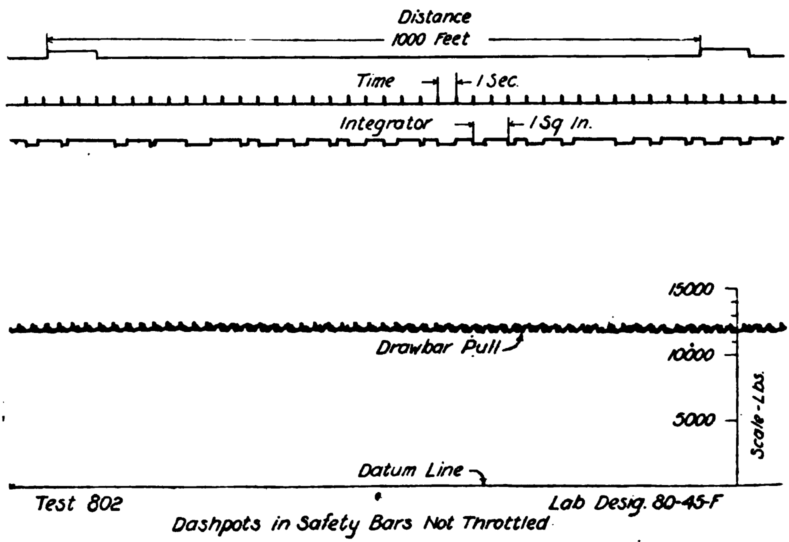
Typical Indicator Diagrams, Locomotive No. 3000.



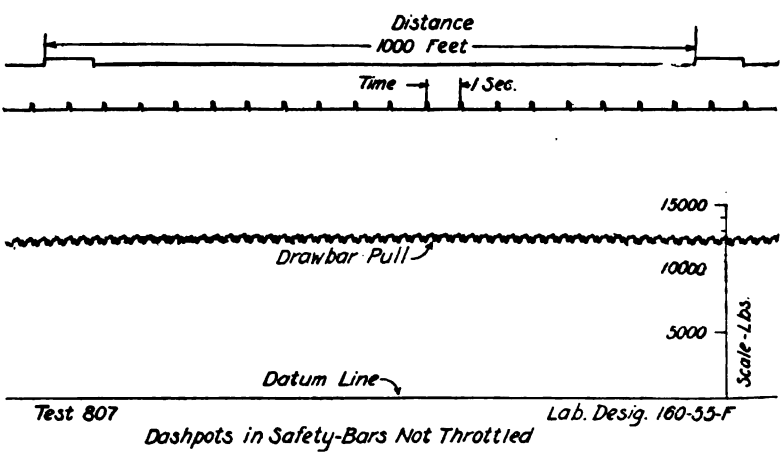
Typical Indicator Diagrams, Locomotive No. 8000.



Typical Indicator Diagrams. Locomotive No. 3000.

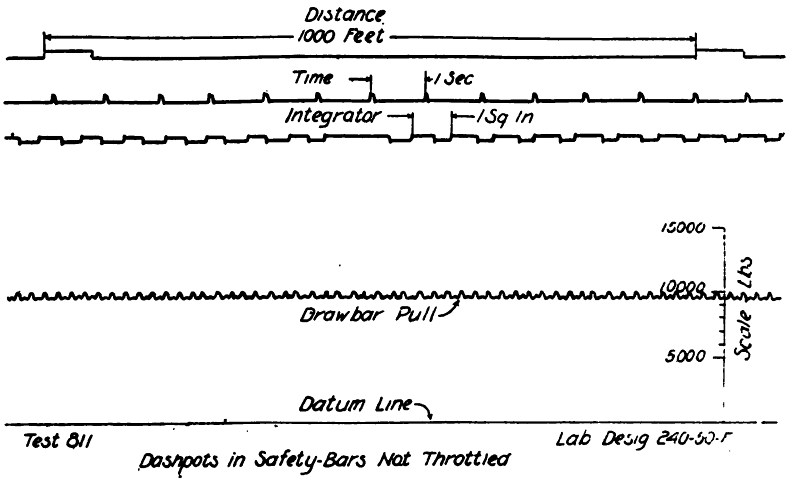


Speed, 18.76 Miles per Hour.

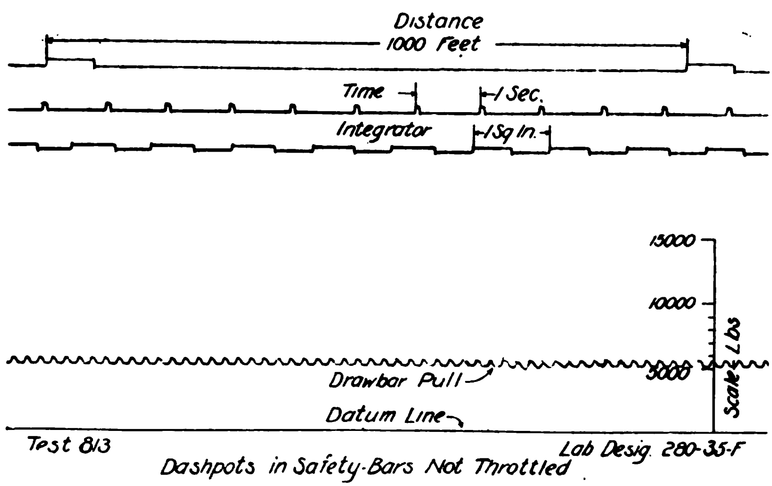


Speed, 37.52 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 3000.

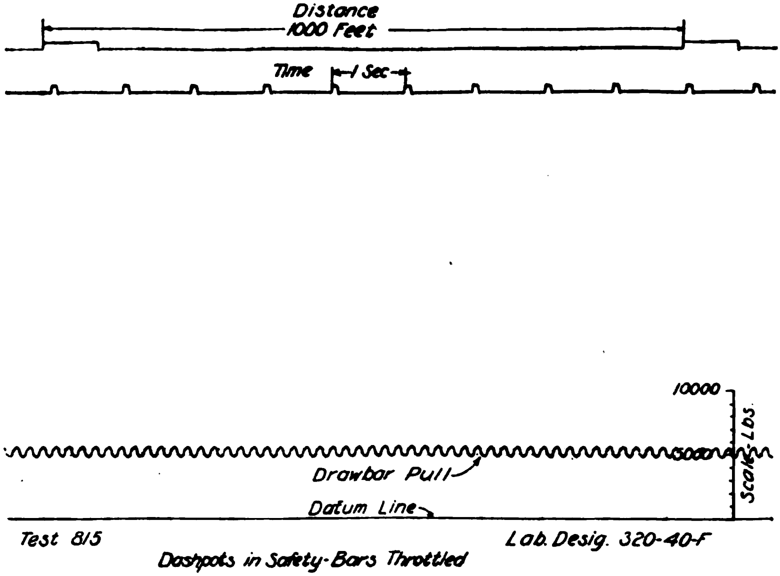


Speed, 56.28 Miles per Hour.



Speed, 65.69 Miles per Hour.

Typical Dynamometer Diagrams, Locomotive No. 3000



Speed, 75.05 Miles per Hour.

Typical Dynamometer Diagram, Locomotive No. 3000.

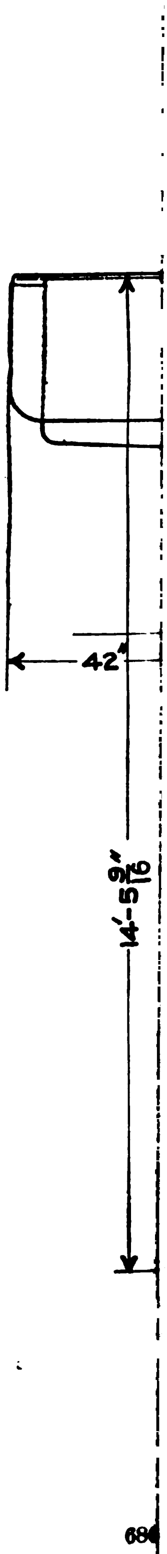


Fig. 812.

CHAPTER XXI.

COMPARISONS AND CONCLUSIONS.

The chief purpose of the tests was to establish with accuracy the actual performance of certain typical locomotives, and this has been satisfactorily accomplished.

It is to be regretted that on account of lack of time it was impossible to test more locomotives, or to duplicate tests.

The complete data obtained from all the tests of each locomotive are presented in previous chapters. It should be kept in mind in making comparisons that in all tests a uniform grade of friable coal having about 75 per cent. fixed carbon and 16 per cent. volatile matter and from the same mine, was used.

In the following pages comparisons are made between the locomotives, and the conclusions which the results of the tests justify are pointed out.

In the diagrams which follow, each locomotive is designated by its number, the significance of which is given in Table C1.

To aid in considering the results, a number of the more important ratios and dimensions are given, although in many cases the relation of these ratios to the results is not apparent.

The distribution of the total weight of each locomotive is shown by Fig. C1.

The freight locomotives Nos. 1499, 585 and 734 had nearly the same total weight and weight on drivers; the passenger locomotives Nos. 535 and 3000 had about the same total weight but the latter had 10,000 pounds more weight on drivers.

The calculated maximum tractive efforts are shown by Fig. C2, but these values were not reached in the tests, for the reasons explained in previous chapters.

TABLE No. C 1.

Loco. No.	Presented for test by	Service	Wheel Arrangement	Simple or Compouud
1499	P. R. R.	Freight	2-8-0	Simple
734	L.S. & M.S.Ry.	"	2-8-0	"
585	Mich. Central	"	2-8-0	Schenectady Two-Cylinder Compound.
929	A.T. & S.F.Ry.	"	2-10-2	Baldwin Tandem Compound.
535	A T.& S.F.Ry.	Pass'ger	4-4-2	Vauclain Four-Cyl. Balanced Compound.
628	Hanover Loco. Works	"	4-4-2	Hanover Four-Cyl. Balanced Compound with Pielock superheater.
3000	N. Y. C. & H. R. R. R.	"	4-4-2	Cole Four-Cylinder Balanced Compound.
2512	P. R. R.	"	4-4-2	De Glehn Four-Cyl. Balanced Compound.

The water and steam space and the total boiler volume are shown in Fig. C5 and Table C2 gives the percentage that the steam space bears to the total boiler volume. Typical ratios applying to the several boilers are shown in Table C3 while in Table C4 the ratios between the same primary factors and

TABLE No. C 2.

Loco. Number		Boiler Volume, Cubic Ft.	Steam Space in Boiler with Water Level at Second Gauge Cock	
			Cubic Ft.	Per cent of Boiler Vol.
Freight	929	657.40	94.60	14.39
	1499	443.39	78.66	17.74
	734	421.73	79.91	18.95
	585	373.20	71.37	19.12
Passenger	535	489.35	54.85	11.21
	3000	409.07	77.41	18.92
	2512	295.85	75.69	25.58
	628	245.30	58.08	23.67

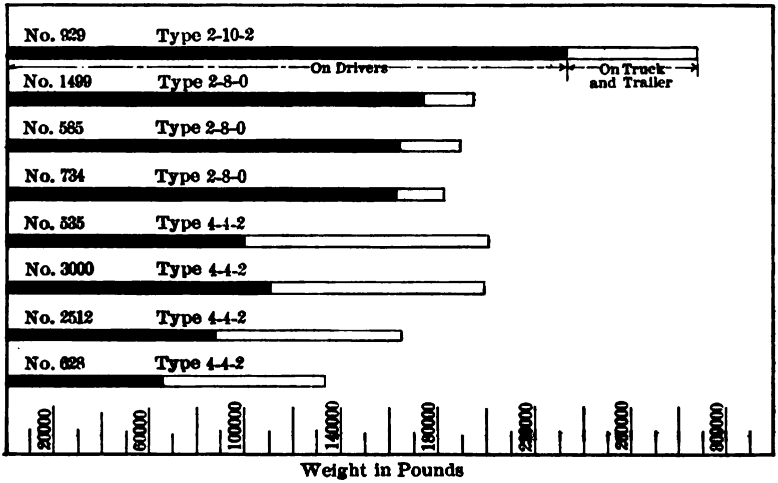


Fig. C 1.—Weights of Locomotives.

TD* are given. The ratios are arranged in order according to their numerical magnitude.

The distance from the highest point of the crown sheet to the highest point of the roof sheet of each locomotive is shown in

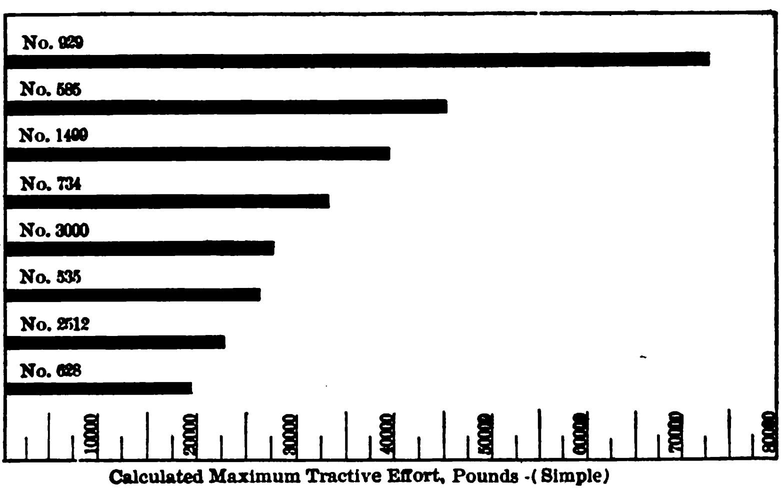


Fig. C 2.—Tractive Efforts.

---

* The term T. D. which is the product of the tractive effort and the diameter of drivers is theoretically proportional to the cylinder power.

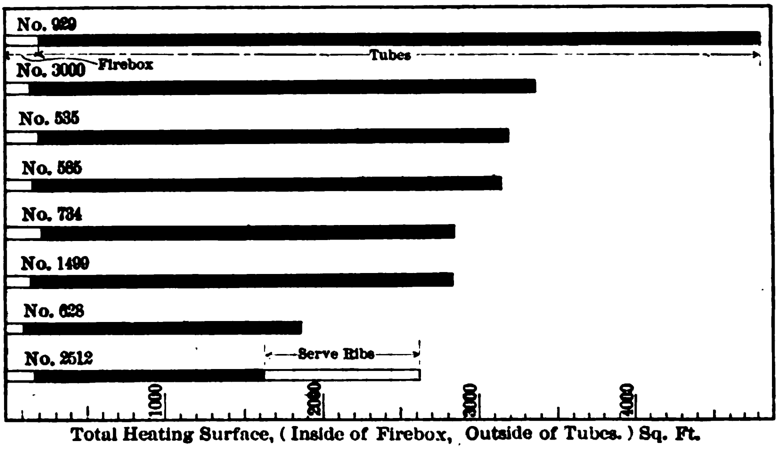


Fig. C 3.—Heating Surfaces.

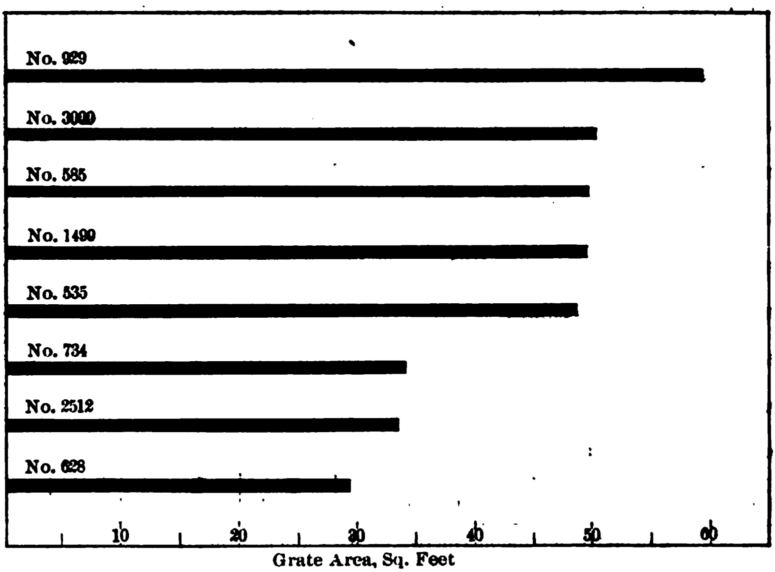


Fig. C 4.—Grate Areas.

TABLE No. C 3.

	Locomotive Number	Ratio of Heating Surface (fire side) to Grate Area	Locomotive Number	Ratio of Fire Area Through Tubes to Grate Area	Locomotive Number	Ratio of Fire-box Heating Surface to Grate Area	Locomotive Number	Ratio of Tube Heating Surface (fire side) to Fire Box H. S.	Locomotive Number	Ratio of Fire Box Volume to Grate Area
Freight	734	75.97	734	.169	734	6.48	929	18.90	734	6.46
	929	73.73	929	.147	929	3.70	585	16.01	929	5.36
	585	57.03	585	.124	1499	3.38	1499	13.91	1499	4.52
	1499	50.44	1499	.124	585	3.35	734	10.61	585	3.60
Passenger	2512	79.56	2512	.141	2512	5.31	3000	18.77	535	5.84
	628	60.33	3000	.136	535	4.56	2512	13.98	2512	5.10
	3000	60.12	535	.123	628	3.63	628	12.92	3000	4.41
	535	60.01	628	.085	3000	3.04	535	12.17	628	3.84

TABLE No. C 4.

	Locomotive Number	Ratio of T. D. to Total Heating Surface (fireside)	Locomotive Number	Ratio of T. D. to Fire Area Through Tubes	Locomotive Number	Ratio of T. D. to Fire-box Heating Surface (fireside)	Locomotive Number	Ratio of T. D. to Fire-box Volume
Freight	1499	897.28	929	419390	929	16612.00	929	11484.00
	929	834.67	734	370895	1499	13385.11	585	11276.10
	734	833.38	1499	365729	585	12104.00	1499	10015.68
	585	711.47	585	327210	734	9673.89	734	9714.71
Passenger	628	613.49	628	430190	3000	10723.25	628	9637.47
	3000	542.19	2512	284861	628	10186.02	2512	7849.12
	535	523.89	535	255093	2512	7536.10	3000	7381.91
	2512	502.92	3000	249863	535	6901.29	535	5386.55

TABLE No. C 5.

Locomotive Number	Distance Inside of Boiler from Highest Point of Crown Sheet to Highest Point of Roof Sheet, in Inches.
929	24.00*
734	21.75*
535	21.50*
3000	21.06
628	20.59
585	19.31
1499	18.25
2512	18.00

*Scaled from drawings.

Table C5. Some of these dimensions were given on the working drawings while others had to be scaled from the blue prints and may not, therefore, be strictly accurate.

COMPARISON OF BOILERS.

All the locomotives, with the exception of No. 929, were at some time during the tests worked to the limit of boiler capacity. The maximum capacity of each of the boilers measured in terms of equivalent evaporation per square foot of fire heating surface per

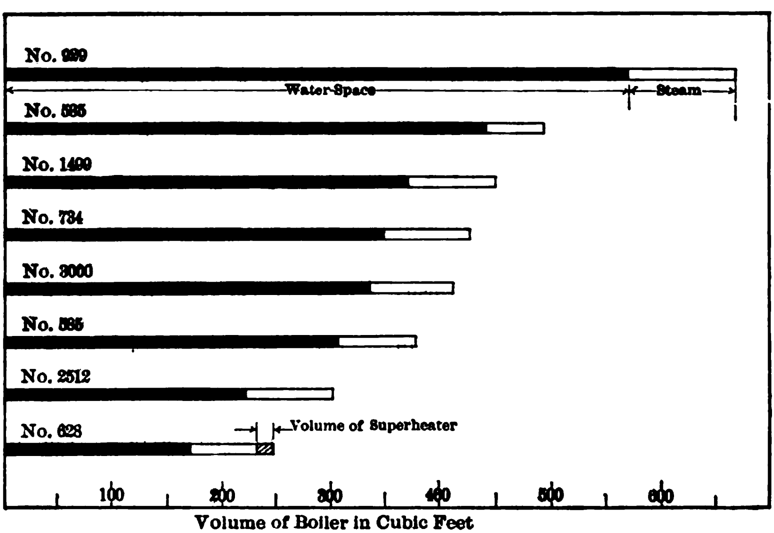


Fig. C 5.—Boiler Volumes.

hour, is shown by Fig. C6. These rates of evaporation were maintained for at least one hour. The boiler of locomotive No. 3000 had the greatest capacity of any tested, having maintained an equivalent evaporation of over 16 pounds of water per square foot of fire-heating surface per hour. The higher figure, shown in light lines, for locomotive No. 2512, has been calculated by not including the heating surface of the ribs in the Serve tubes, with which the boiler was fitted.

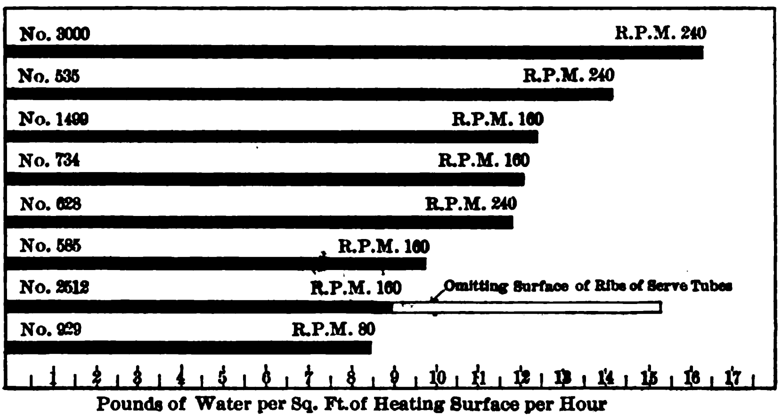


Fig. C6.—Maximum Boiler Capacities.

Fig. C7 shows the capacity of the boilers. No. 2512, which was equipped with Serve tubes, had uniformly the smallest capacity, which makes it appear that the heating surface of the Serve ribs is not equal to ordinary tube heating surface in capacity.

The relative advantage of large and small grates is not definitely settled, but the results are conclusive in proving that the furnace losses, due to excess air, are not greater with the large grate, when properly fired, than in the case of the small grate.

The ratios of heating surface to grate area, Table C3, show that locomotives Nos. 734 and 929 had relatively small grates, and an examination of Fig. C7 shows that for equal rates of combustion per square foot of grate, their capacity was distinctly less than the boilers with larger grates.

From the fact that locomotives Nos. 585 and 3000 had much smaller fire-box heating surface than the others, it would appear

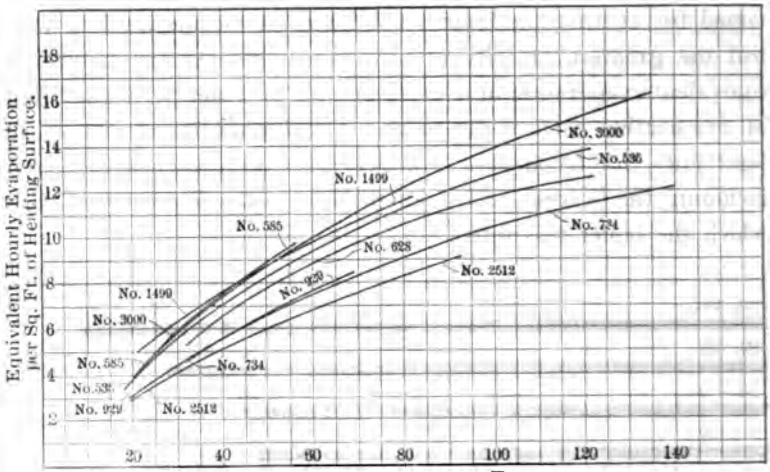


Fig. C 7.— Boiler Capacities.

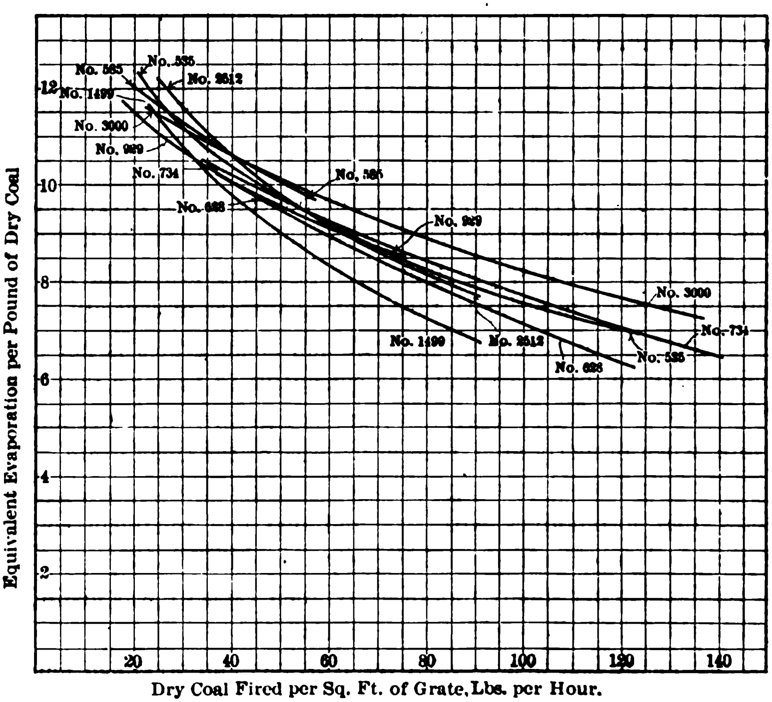


Fig. C 8.— Boiler Efficiencies Referred to Coal per Sq. Ft. of Grate.

that there was no special advantage in large fire-box heating surface; probably the tube heating surface, if ample, will absorb the heat not taken up by the fire-box.

In Fig. C8 locomotive No. 2512 assumes an average position, but in Fig. C9 where the economy is plotted in relation to the coal

TABLE No. C 6.

	Loco. No.	Fire-Box Temperatures		Smoke-Box Temperatures	
		Maximum	Minimum	Maximum	Minimum
Freight	784	2312	1885	669	518
	1499	2112	1427	757	561
	929	1986	1507	574	419
	585	1739	1059	622	493
Passenger	3000	2339	1856	743	512
	628	2258	1950	787	561
	585	2177	1476	689	500
	2512	2044	1588	594	483

per square foot of heating surface per hour, locomotive No. 2512 gives the lowest results, which tend to confirm the statement already made concerning the value of Serve ribs.

Locomotives Nos. 2512 and 628 had copper fire-boxes, but no advantage either in economy or capacity can be traced to this cause.

TABLE No. C 7.

	Loco. No.	Boiler Efficiency	
		Maximum	Minimum
Freight	1499	78.93	45.37
	585	78.42	60.41
	929	74.62	54.69
	784	71.34	41.81
Passenger	2512	78.55	51.35
	535	78.43	44.05
	3000	75.34	46.89
	628	63.30	39.55

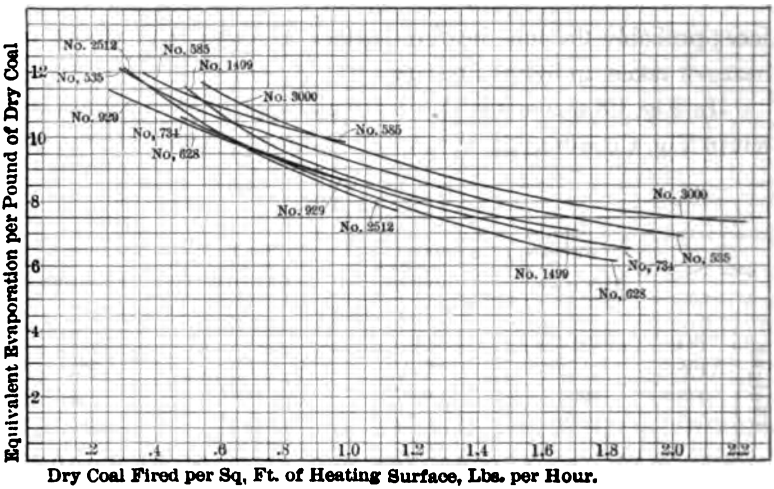


Fig. C 9.—Boiler Efficiencies Referred to Coal per Sq. Ft. of Heating Surface.

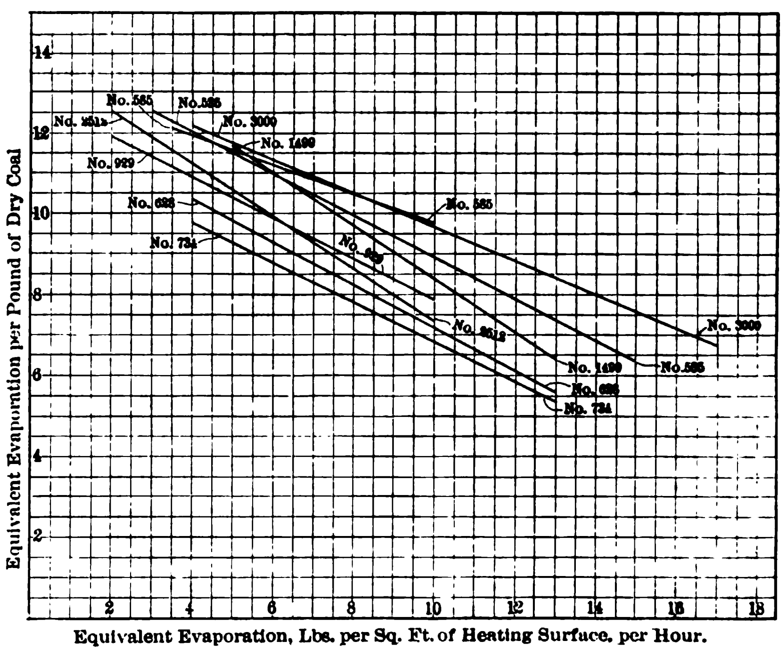


Fig. C10.— Equivalent Evaporation.

Table C6 gives the maximum and minimum fire-box and smoke-box temperatures obtained.

Comparing these results with stationary practice will show that there is no excessive loss of heat due to high smoke-box temperature, even at the higher rates of combustion and the smoke-box temperatures obtained when the locomotives were working at the average horse powers show very satisfactory results as compared with stationary work.

There is a great variation in boiler efficiency at varying rates of combustion, the maximum and minimum percentage of boiler efficiency being given in Table C7.

At very low rates of combustion, No. 585 gave the best results in economy; at higher rates, locomotive No. 3000 was the best.

In all cases the highest efficiency is obtained with the smallest or nearly the smallest horse power and the efficiency rapidly decreases as the horse power is increased. A study of these tables shows conclusively the desirability of large boiler capacity, in relation to the average work expected from the locomotive.

An examination of these efficiencies in connection with the horse power developed shows that the locomotive boiler compares favorably in efficiency with good stationary practice, while capable of developing large overload horse power for emergencies, at a sacrifice of economy.

The relation between dry coal fired per square foot of grate per hour and per cent. of carbon monoxide, CO, in the smoke-box gases, is shown in Fig. C11. It will be noted that the locomotives seem to fall in two groups; Nos. 929, 1499, 628 and 585 show large percentages of CO in the smoke-box gases, while Nos. 2512, 535, 3000 and 734 show relatively small percentages of CO.

The fire-box temperatures at different rates of combustion which are plotted on Fig. C12, indicate that, with the exception of locomotive No. 628, the per cent. of CO bears some relation to the fire-box temperature; that is to say, Nos. 585, 1499 and 929 had the lowest fire-box temperatures and the highest percentages of CO, while locomotives Nos. 3000, 734 and 535 had the highest fire-box temperatures and the lowest percentages of CO. The high fire-box temperature of locomotive No. 628 and the large percentage of CO, which are an apparent contradiction to the results of the other boilers, may be partly explained by the poor distribu-

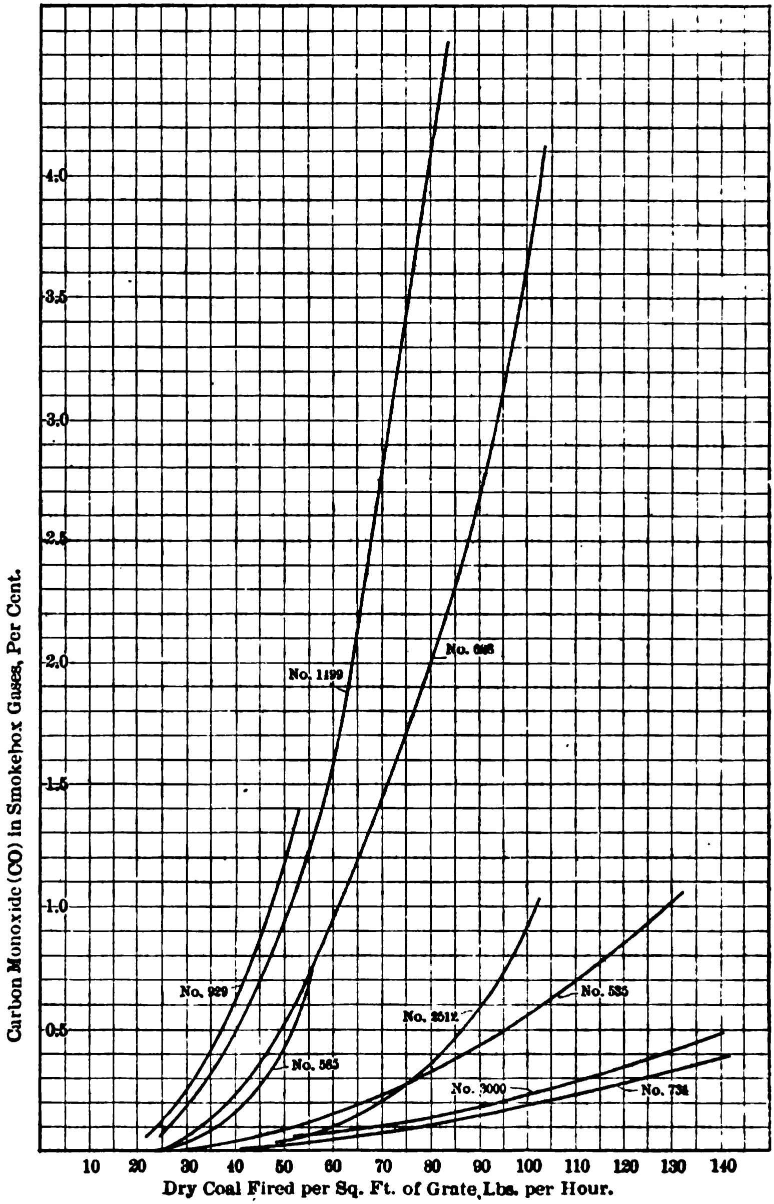


Fig. C 11.

Carbon Monoxide in Smokebox Gases.

tion of the draft in the fire-box, so that the combustion was unequally distributed.

The high temperatures noted in the boilers with brick arches are probably due to the heated arch, which would form a better combustion chamber than the relatively colder surfaces of the fire-box. It is to be expected also that when there is a high temperature, the CO would be small. It may, therefore, he said that a brick arch will make possible a higher fire-box temperature, and thus decrease the percentage of CO.

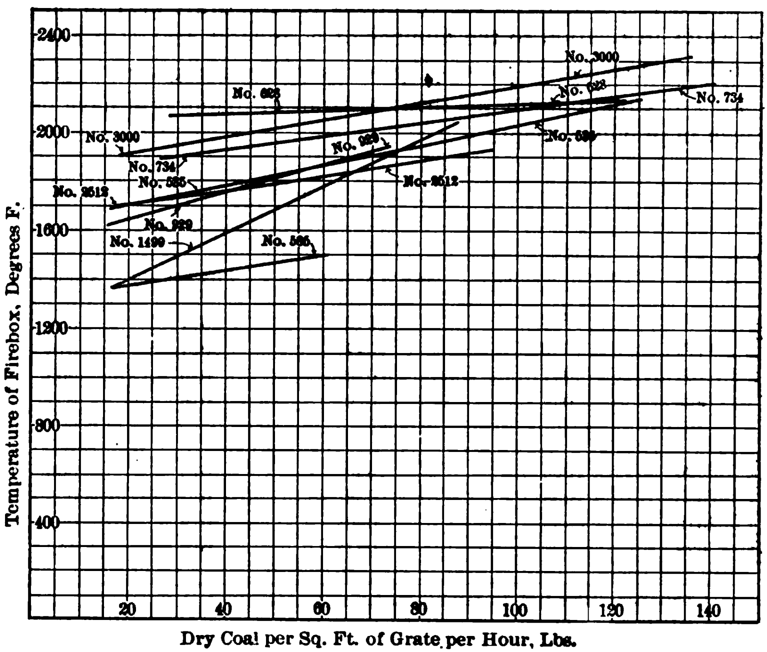


Fig. C 12.— Firebox Temperatures.

It should be noted that locomotives Nos. 585, 2512, 535, 3000 and 734 had brick arches, and locomotives Nos. 1499 and 929 did not, No. 628 having an arch so small as to be of very little value.

The maximum percentage of loss of heat due to imperfect combustion of CO is summarized in Table C8.

These results would tend to show that in the majority of the boilers tested the losses due to this cause were not serious.

TABLE No. C 8.

	Loco. No.	Loss. Percent.		Loco. No.	Loss, Percent.
Freight	1499	16.83	Passenger	628	16.12
	585	3.31		535	4.57
	929	2.28		2512	4.43
	734	2.09		3000	1.25

DRAFT.

The co-efficients of the equations for the draft (D) in inches of water in relation to the number of pounds of coal (G) burned per hour per square foot of grate surface are given in Table C9. The equations for the draft in front of diaphragm have been given in previous chapters.

TABLE No. C 9.

	Loco. No.	Coefficients of Draft			
		Front of Diaphragm	Back of Diaphragm	Fire-box	Ash-pan
Freight	585	.058	.042	.017	.002
	1499	.049	.044	.027	.018
	734	.047	.026	.010	.002
	929	.044	.029	.016	.007
Passenger	3000	.066	.045	.016	.006
	535	.058	.038	.017	.005
	2512	——	.038*	.013	.002
	628	——	.034*	.016	.003

* This locomotive had no diaphragm in smoke box.

The difference between any two coefficients is proportional to the reduction of pressure between the corresponding portions of the boiler. These differences are given in Table C10.

The draft in the ash-pan would depend chiefly on the area of the air openings in ash-pan in proportion to the area of grate.

Table C11 shows that there is a general relation between these quantities.

It is evident that after a relation of .14 square feet of air inlet per square foot of grate was reached that no further decrease of draft occurred, when the air inlets were increased; and when the air inlets were less than .11 square feet per square foot of grate, the draft necessary to supply air increased very rapidly.

It should not be forgotten that in this particular the tests on the plant do not exactly reproduce road conditions, for the movement of the locomotive in actual service would, undoubtedly, force a larger supply of air through the front damper than would be the case on the plant.

TABLE No. C 10.

Locomotive Number		Differences in Coefficients between		
		Front and Back of Diaphragm	Back of Diaphragm and Fire-box	Fire-box and Ash-pan
Freight	734	.021	.016	.008
	585	.016	.025	.015
	929	·015	.013	.009
	1499	.005	.017	.009
Passenger	3000	.021	.029	.010
	535	.020	.021	.012
	2512	——	.025	.015
	628	——	.018	.011

The difference in the draft between the ash-pan and fire-box will depend on the thickness of the bed of coal and the air open-

TABLE No. C 11.

Loco. No.		Air Inlets to Ash-pan per Square Foot of Grate	Ash-pan Draft Coefficient
Freight	1499	.0774 Sq. ft.	.018
	929	.1274 " "	.007
	734	.1445 " "	.002
	585	.1614 " "	.002
Passenger	3000	.0972 " "	.006
	535	.1342 " "	.005
	628	.1142 " "	.003
	2512	·1422 " "	.002

ings in the grates, and these figures, which are given in Table C10, do not bear any evident relation to the ratios of air openings in grates to grate area. The average difference of draft between the ash-pan and fire-box is .011.

The loss of draft in the flues will evidently depend on the length of flues, the inner periphery, the total number and the velocity of the gases passing through them.

The difference in the draft between the two sides of the diaphragm gives an indication of the influence of different front end arrangements. Locomotives Nos. 734, 535 and 3000 had self-

TABLE No. C 12.

	Loco. No.	Quality of Steam	
		Maximum	Minimum
Freight	1499	.9903	.9877
	734	.9871	.9837
	929	.9846	.9445
	585	.9845	.9828
Passenger	628	.9986	.9936
	2512	.9859	.9812
	3000	.9835	.9499
	535	.9823	.9626

cleaning front ends, and the results show that this arrangement offers considerable resistance to the passage of the gases.

Locomotives Nos. 2512 and 628 required less draft per pound of coal than any of the other locomotives, probably on account of the absence of obstructions in the smoke-boxes.

The results of the tests show that the steam delivered by the locomotive boiler was practically dry under average running conditions, and comparison with item 229 shows that the steam was further dried in its passage to the cylinders; this was especially true in throttling tests. The tables indicate that the percentage of moisture in steam from locomotive boilers under average conditions is 1½ per cent.

Reference to the last column in Table C12 shows that considerable priming occurred in locomotives Nos. 929, 535 and 3000. As the water used in the boilers was chemically treated to purify it, a certain amount of sodium sulphate and other salts found their way into the boiler, which when concentrated, caused foaming. It was not possible to blow out the boilers frequently, so this trouble could not always be avoided; in particular the priming of locomotive No. 929 was due to this cause.

The average number of British Thermal Units in the coal, cinders and sparks is given in Table C13.

The results of the tests show the enormous power to which a locomotive boiler may be worked, the normal action of such boilers involving the delivery of approximately 12 pounds of steam per foot of fire-heating surface per hour, and in one case,

TABLE No. C 13.

Locomotive Number		Average British Thermal Units, in one Lb. of		
		Coal	Cinders	Sparks
Freight	929	15007	11199	8877
	585	14913	12159	10271
	734	14907	11877	11161
	1499	14141	10470	8184
Passenger	628	14993	13901	12563
	3000	14989	12493	11995
	535	14967	12139	11577
	2512	14916	12391	11595
Average		14855	11992	10777

as much as 16 pounds; that whereas in stationary practice it is customary to allow about 10 feet of heating surface per boiler horse power, in these locomotives between 2 and 3 feet only were required.

The economy also was good in a number of tests, the equivalent evaporation per pound of coal being 12 pounds and in only a few cases as low as 6 pounds.

COMPARISON OF ENGINES.

The results show that the modern simple freight locomotive, of the types tested, can be depended upon to develop continuously from 1000 to 1100 horse power. The limit of power under constant conditions of running for the modern compound passenger locomotive may exceed 1600 horse power. The maximum indicated horse power for each locomotive is shown in Table C14.

TABLE No. C 14.

	Loco. No.	Maximum Indicated Horse Power		Loco. No.	Maximum Indicated Horse Power
Freight	929	1258	Passenger	3000	1641
	734	1098		535	1622
	1499	1050		2512	945
	585	1041		628	816

Particularly significant is the high economy which attends the action of the simple locomotive, over a wide range of action; for all speeds and cut-offs commonly employed upon the road, the variation in cylinder performance falling between the limits of 23.4 and 28.3 pounds of water per indicated horse power hour.

TABLE No. C 15.

Simple Freight Locomotives	1499	734	Average
Minimum Water per Indicated Horse Power Hour	23.43	23.92	23.67
Water per Indicated Horse Power Hour, Maximum Load	23.74	23.92	23.83
Water per Indicated Horse Power Hour, Maximum Consumption	28.33	29.56	28.95

The compound locomotives tested when running under all speeds and cut-offs gave an indicated horse power hour in return for the consumption of from 18.6 to 27 pounds of steam; with the superheater locomotive No. 628 the minimum consumption was reduced to 16.6 pounds of superheated steam per hour.

The steam consumption of the freight locomotives, in relation to indicated horse power, is plotted in Fig. C13.

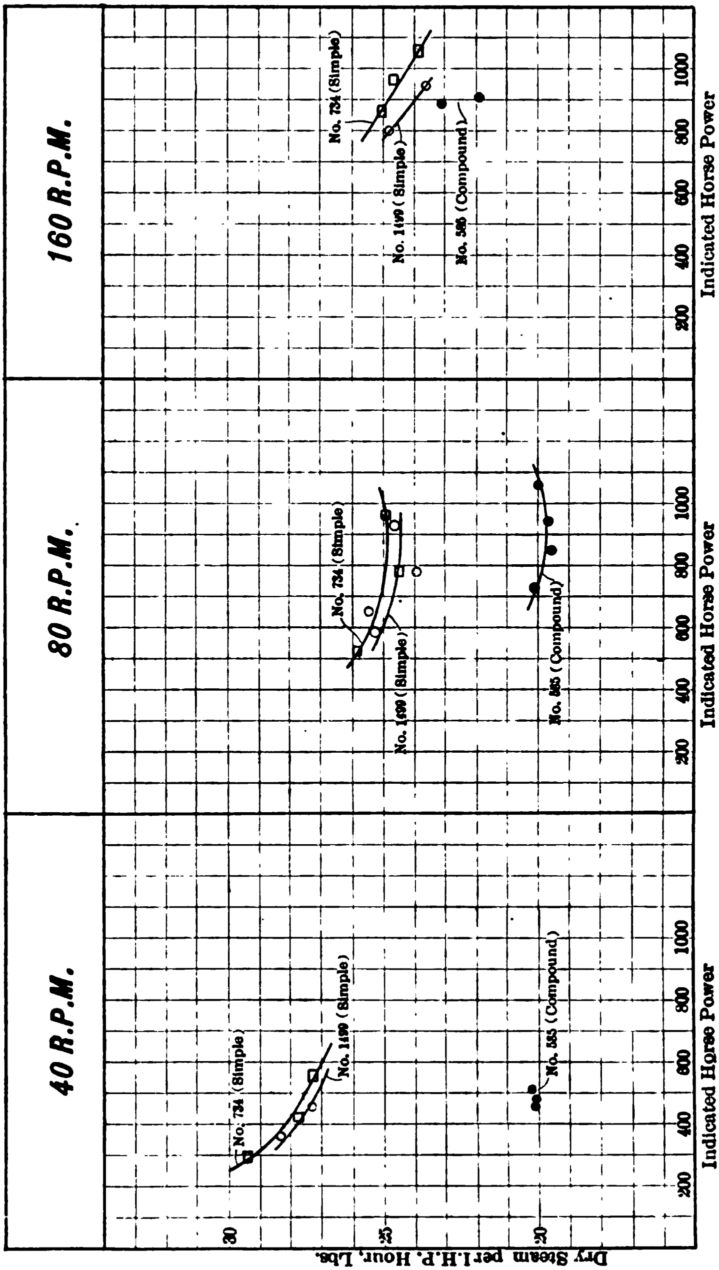


Fig. C 13.—Steam Consumption, Freight Locomotives.

At all speeds the engines of the cross compound locomotive No. 585, were the most economical, although the advantage of the compound decreased with increase of speed.

TABLE No. C 16.

Compound Locomotives	Minimum Water per Indicated Horse Power Hour	Water per Indicated Horse Power Hour, Maximum Load	Water per Indicated Horse Power Hour, Max. Consumption
585	19.54	20.03	24.14
929	20.98	24.04	26.47
2512	18.60	20.67	27.05
535	19.41	20.48	23.67
628†	16.60	18.80	21.29
628*	17.82	20.26	22.77
3000	19.60	24.14	24.14
Average Freight	20.26	22.03	25.31
" Passenger	18.86	21.39	24.41

† Superheated steam.

* Saturated steam, calculated from the quantity of superheated steam used.

By averaging the steam consumption for each locomotive at each speed, we obtain Table C17, the consumption for engine No. 585 being taken as unity.

This table shows that at the higher speeds the advantage of the compound is very small, in fact by examination of Fig. C14, there would be no difference at about 200 revolutions per minute.

In general, the steam consumption of the simple engines decreased with increase of speed, while that of the compounds in-

TABLE No. C 17.

Freight Loco. No.	40 R. P. M.	80 R. P. M.	160 R. P. M.
585	1.00	1.00	1.00
929	1.23	1.15	——
1499	1.38	1.25	1.06
734	1.40	1.27	1.07

creased, which would lead to the conclusion that the steam distribution of the compounds was less satisfactory at high speeds than that of the simple locomotives.

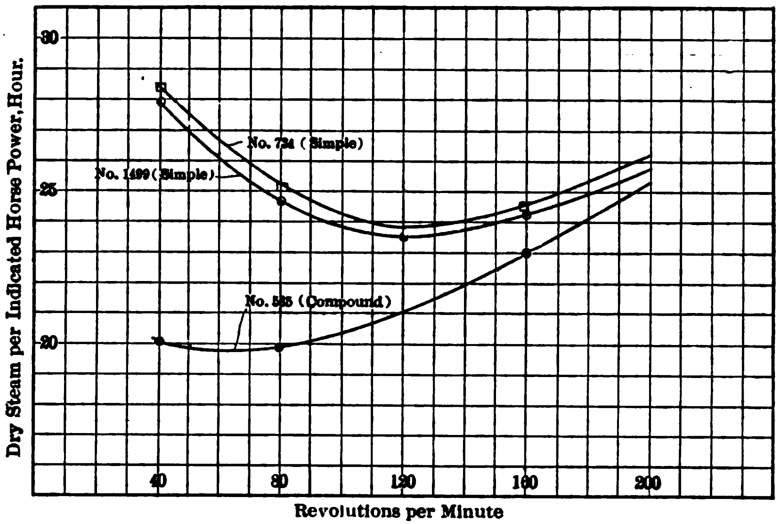


Fig. C 14.— Average Steam Consumption, Freight Locomotives.

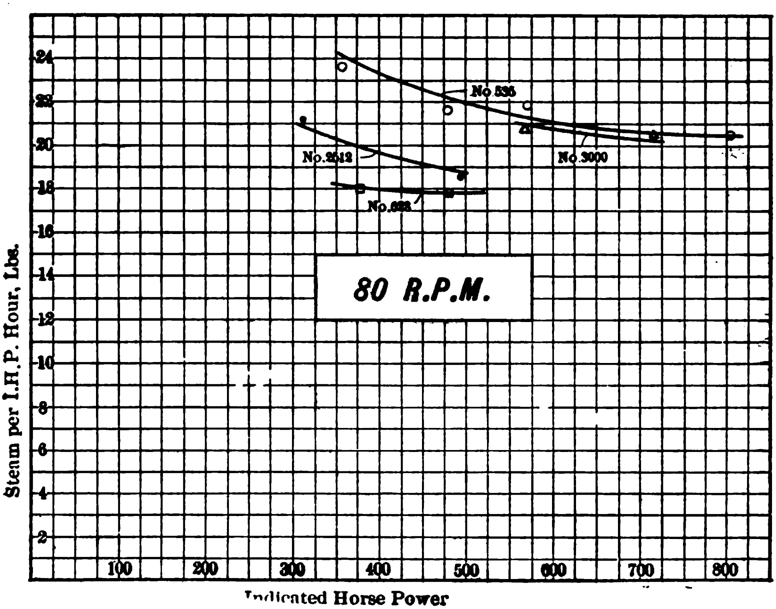


Fig. C 15.— Steam Consumption, Passenger Locomotives.

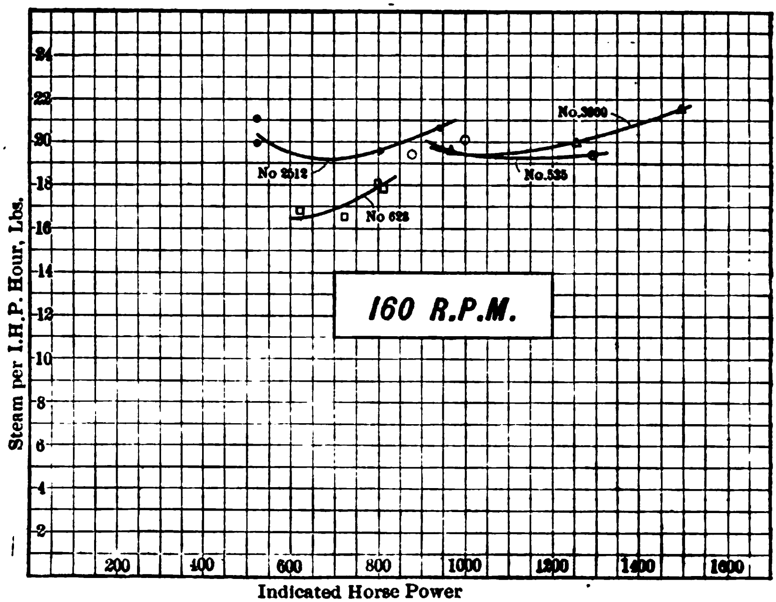


Fig. C 16.— Steam Consumption, Passenger Locomotives.

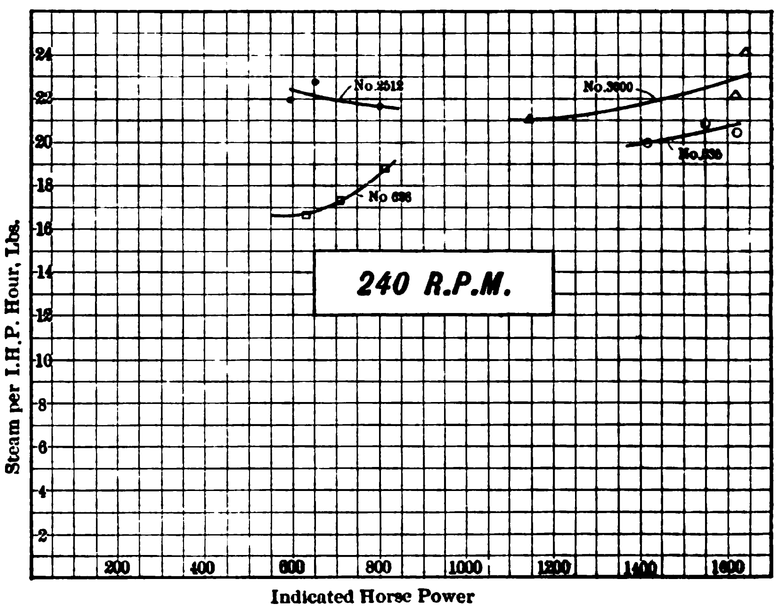


Fig. C 17.— Steam Consumption, Passenger Locomotives.

The steam consumption of the four passenger locomotives at 80, 160 and 240 revolutions per minute is shown by Figs. C15, C16 and C17 respectively. Locomotive No. 628, which in all cases gave the best performance, used superheated steam. It will be noted, however, that the steam consumption increased very rapidly as the power developed increased. At 80 revolutions per minute locomotive No. 2512 gave better results than Nos. 535 and 3000. At 160 revolutions per minute No. 535 used less steam per indicated horse power hour than No. 2512.

At 240 revolutions per minute No. 535 used nearly 10 per cent. less steam than either No. 2512 or No. 3000.

Averaging the consumption at each speed, and taking No. 628 as unity, we have:

TABLE No. C 18.

Passenger Loco. No.	80 R. P. M.	160 R. P. M.	240 R. P. M.	280 R. P. M.
2512	1.11	1.17	1.26	1.27
535	1.22	1.18	1.16	.97
628†	1.00	1.00	1.00	1.00
628*	1.07	1.07	1.06	1.07
3000	1.15	1.17	1.28	1.04

† Superheated steam. * Saturated steam, calculated.

It should be remembered that locomotive No. 2512 was equipped with two reverse screws so that the cut-off in the high and low-pressure cylinders could be varied independently. Locomotive No. 628 had a constant difference of cut-off in the high and low-pressure cylinders of about 17 per cent., while Nos. 535 and 3000 had the same cut-off in both cylinders.

With all the engines, except No. 3000, there was only one test at 280 revolutions per minute and that on No. 628 was very short (30 minutes), so that the absence of checking tests renders the data at this speed less valuable than at the other speeds.

This data is shown graphically on Fig. C18.

Throttling tests were made only on the first three locomotives, and while the steam was slightly superheated by wire-drawing, any considerable amount of throttling did not prove as economical as running with open throttle and shorter cut-off. Very small throttling had no appreciable effect.

The maximum indicated horse power per square foot of grate surface is given in Table C19.

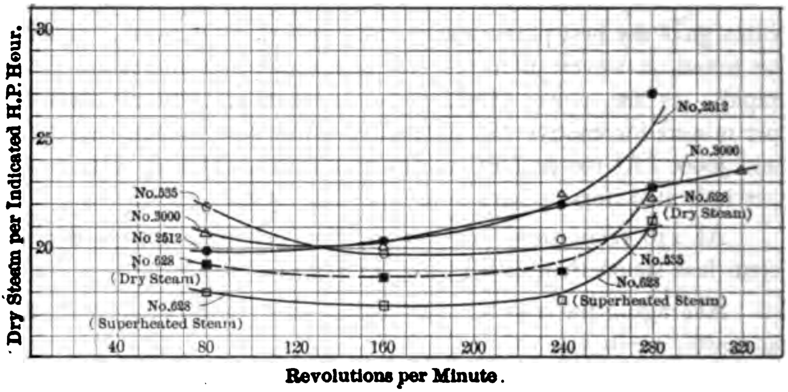


Fig. C 18.— Average Steam Consumption, Passenger Locomotives.

The ratio of cylinder volumes and the percentage of clearance are given in Table C20.

It is noteworthy that the ratio of cylinder volumes was less

TABLE No. C 19.

Loco. No.	Freight Locomotives, Maximum Indicated Horse Power per Sq. Ft. of Grate Surface.	Loco. No.	Passenger Locomotives Maximum Indicated Horse Power per Sq. Ft. of Grate Surface.
734	31.22	535	33.58
929	21.54	3000	32.90
1499	21.05	2512	28.29
585	21.05	628	28.09

for No. 628 than it was for the other four-cylinder compounds. This ratio on No. 585 was probably limited by the permissible width across cylinders.

COMPARISON OF LOCOMOTIVES.

A study of the data showing the steam consumption per indicated horse power hour, as well as steam and coal per dynamometer horse power hour, indicates that the performance of the steam locomotive is far better than is commonly supposed and that the economy compares favorably with that of other methods of traction.

The coal burned has not been corrected for variations in feed water temperature.

The consumption of coal per dynamometer horse power hour of the freight locomotives is shown on Figs. C19, C20 and C21.

TABLE No. C 20.

	Loco. No.	Clearance, per cent of Piston Displacement		Ratio of Cylinder Volumes.
		H. P. Cyl.	L. P. Cyl.	
Freight	929	17.14†	8.37†	2.79
	585	16.68†	5.71*	2.82
	1499	11.29*	—	—
	734	9.26*	—	—
Passenger	3000	16.87†	6.52†	2.84
	2512	13.27*	9.75*	2.82
	535	18.57†	6.58†	2.78
	628	11.72†	10.32*	2.47

* Slide valves. † Piston valves.

The results obtained from No. 585 are, in all cases, the best, the economy of No. 585 decreasing with increase of speed.

Table C21 gives the results at each speed, assuming the figures from No. 585 as unity.

It should be remembered in considering this table that the

TABLE No. C 21.

Freight Loco. No.	40 R. P. M.	80 R. P. M.	160 R. P. M.
1499	1.65	1.75	1.54
734	1.77	1.66	1.36
585	1.00	1.00	1.00
929	1.41	1.34	—

boiler of No. 585 was much more efficient than the other freight locomotive boilers.

The coal consumption per dynamometer horse power hour of the passenger locomotives is shown in Figs. C22, C23 and C24.

At 80 revolutions per minute No. 2512 gave the best results, although No. 628 was equipped with a superheater, but had a relatively poor boiler performance.

At 160 revolutions per minute the economy of all the locomotives was almost the same, but Nos. 535 and 3000 developed higher horse powers than the others. The performance of No. 535 showed less variation in steam consumption for different horse powers than any of the other locomotives.

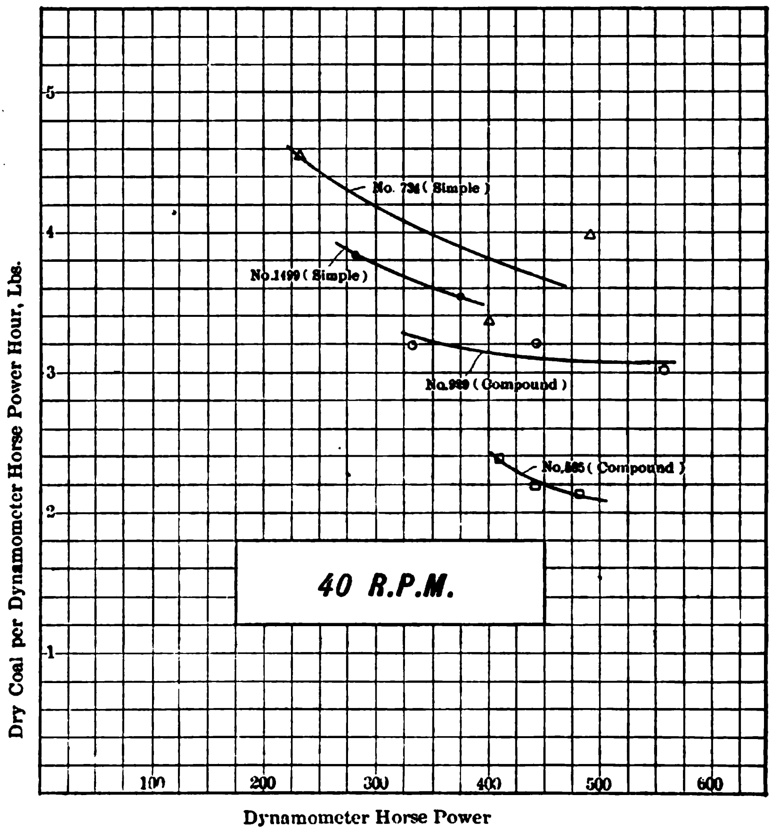


Fig. C 19.—Dry Coal per D. H. P. Hour, Freight Locomotives.

At 240 revolutions per minute the sharp increase in consumption for No. 628 indicated that the locomotive worked at the very limit of its capacity, while the downward inclination of the results of No. 2512 apparently showed that it had not reached the full capacity of the engines, although the boiler was worked until it failed to furnish sufficient steam.

Eliminating tests in which the machine friction was apparently abnormally high, as for instance, test No. 801 of Engine No.

3000, gives maximum and minimum values of machine efficiency for each number of revolutions as follows:

Revolutions.	Maximum.	Minimum.
40	94.06	76.74
80	94.16	79.46
160	93.95	72.89
240	90.20	72.27
280	86.83	61.53
320	78.27	78.27

The figures in the several tables show that the minimum loss due to engine friction is in engine No. 585, or 5.84 per cent.

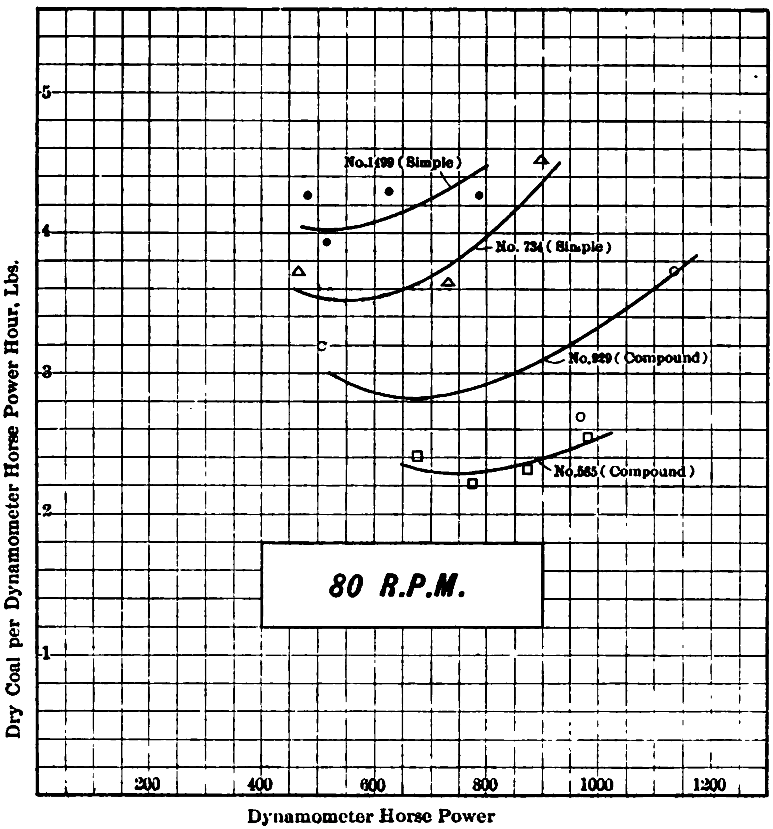


Fig. C 20.— Dry Coal per D. H. P. Hour, Freight Locomotives.

From the tabulated figures above given in connection with the tables under test of each locomotive, an idea can be obtained of the probable loss in engine friction under any given conditions.

All of the tests indicate the desirability of using locomotives

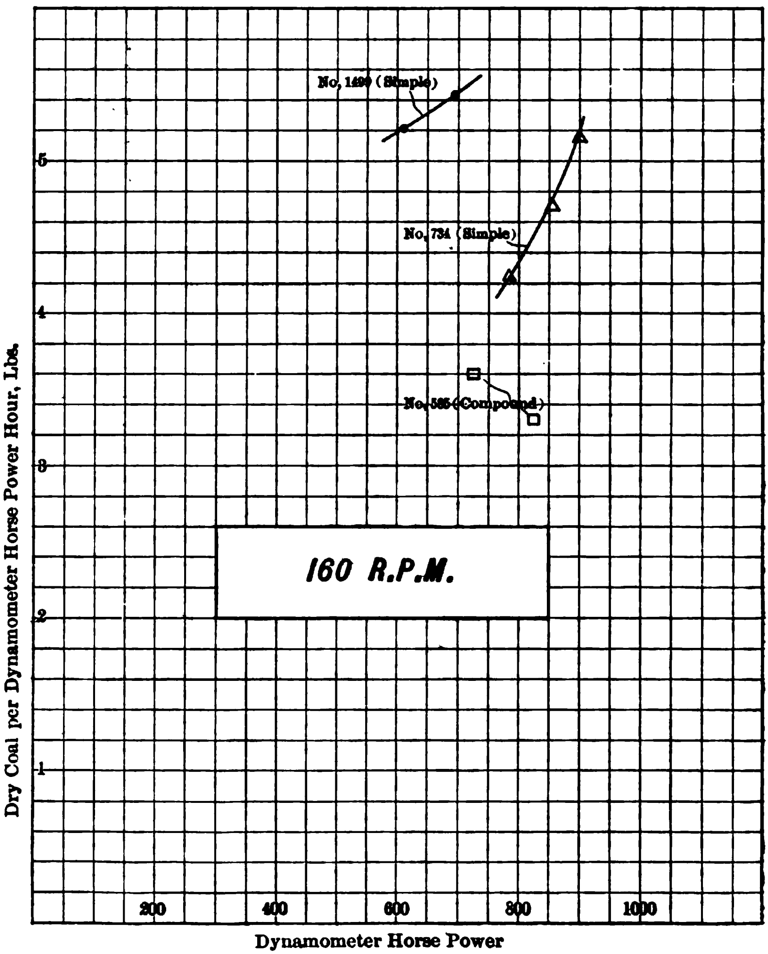


Fig. C 21.— Dry Coal per D. H. P. Hour, Freight Locomotives.

with ample margin of power for the average work to be done, and no disadvantage is shown by these tests in operating locomotives at considerably less than their maximum capacity. In fact, a reduction in horse power is accompanied by a substantial gain in economy. For example, Tables 611, etc., for passenger locomotives Nos. 535 and 3000 show a maximum capacity in dynamo-

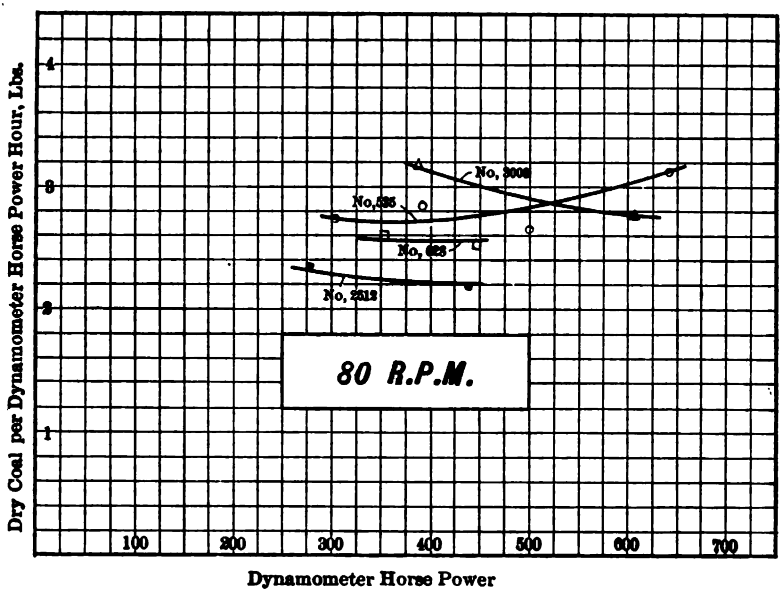


Fig. C 22.— Dry Coal per D. H. P. Hour, Passenger Locomotives.

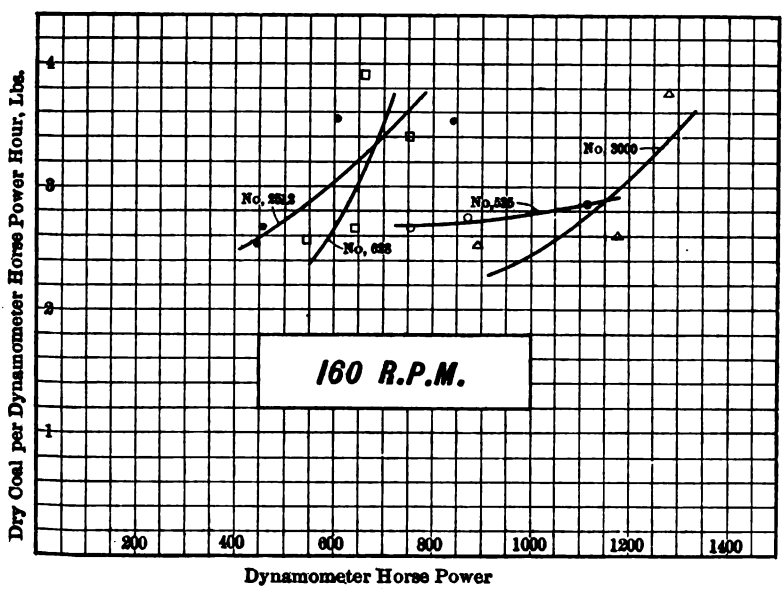


Fig. C 23.— Dry Coal per D. H. P. Hour, Passenger Locomotives.

meter horse power in the case of one engine of over 1300 horse power and in the other case 1475, but these locomotives will be run in actual service with trains requiring a probable average of 1000 dynamometer horse power or less. From the

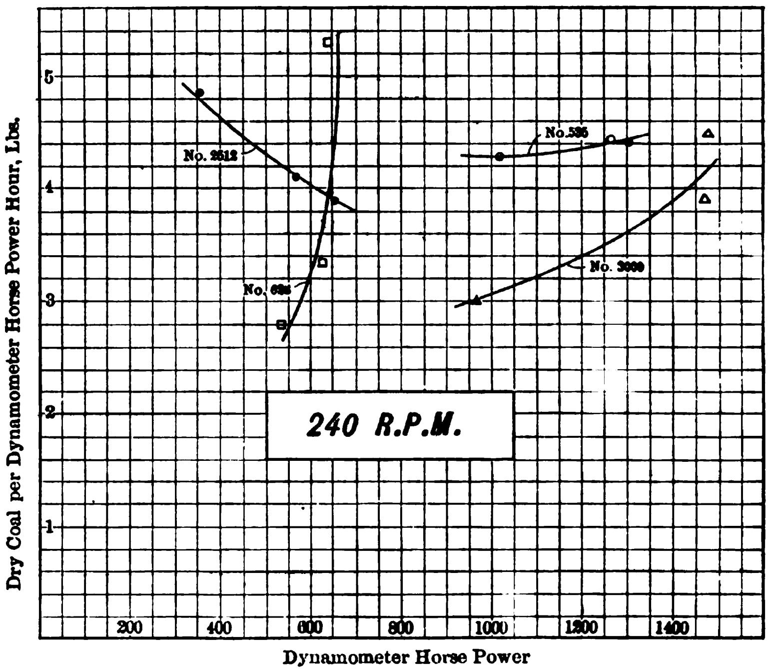


Fig. C24.—Dry Coal per D. H. P. Hour, Passenger Locomotives.

tables it will be seen that both locomotives were considerably more economical at the lower horse power than at the higher, while the capacity for the greater horse power is always available for emergencies.

An examination of Tables 111, etc., column 384, for the remaining engines, both freight and passenger, shows the same characteristics of increased economy with average instead of maximum loads, thus showing that the locomotive is a very flexible machine in its adaptability to railroad requirements.

INFLUENCE OF METHODS OF LUBRICATION.

The principal facts in regard to the lubrication of the locomotives are shown in the following, Table C22.

Where oil lubrication was used for rods and axles it was by means of the customary American methods, except in the case of locomotives Nos. 628 and 2512 which had, instead of waste in the driving box cellars, a lubricating pad held against the axle by springs as is customary in European practice. Where hard grease was used its composition was about as follows:

Oil,	28.66	per cent.
Soap,	55.83	" "
Water,	15.51	" "
	100.00	" "

The cake of hard grease was pressed against the axle journal

TABLE No. C 22.

	Loco. No.	Lubrication of Driving Axles	Lubrication of Connecting Rods	Lubrication of Pistons and Valves
Freight	1499	Grease	Grease	Sight-feed lubricator.
	734	Oil	"	" " "
	585	"	"	" " "
	929	"	"	" " "
Passenger	585	Grease	"	" " "
	2512	Oil	Oil	" " "
	3000	"	"	" " "
	628	"	"	Freidman Force-Feed Lubricator.

by springs located in the bottom of the driving box cellars. A perforated plate between the axle and the cake of grease was used. In the rods the grease was forced against the crank pin journal by means of a screw. The methods in all cases being similar to those in general use.

The friction in terms of draw-bar pull per axle at 80 revolutions per minute is shown on Fig. C25. The plotted points are marked with the locomotive number and with the kind of lubrication used on the driving axles. In plotting these results it immediately became evident that the friction loss at the driving axle journal was so large a factor in the total friction as to obscure the effect of the rod lubrication, whether grease or oil. The heavy horizontal lines are drawn to show the average value for each group of locomotives. The point for No. 3000 is, for this speed, very high, being nearly 1,450 pounds per axle with oil lubrication. By referring, however, to Figs. C26 and C27, this locomotive will be seen to have later taken its position in the group of oil lubricated locomotives. The tests of locomotive No. 3000 at 80 revolutions per minute were run before those at 160 and 240, and after the locomotive had been standing for a number of months in the Transportation Building. From this it may be

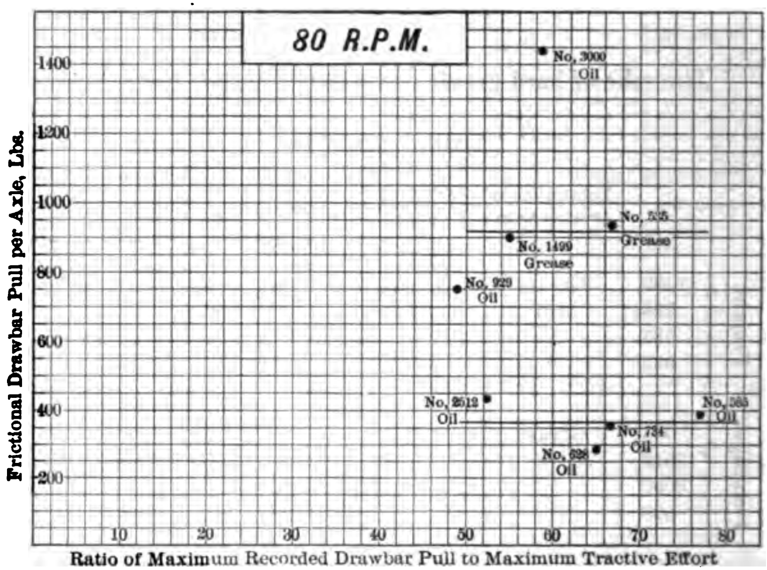


Fig. C 25.— Machine Friction.

assumed that the high friction was caused by the condition of the journal surfaces and that it became normal after the first two tests at 80 revolutions per minute, when the journals had become smooth.

At 160 revolutions per minute (Fig. C26) the grouping is again according to the kind of lubrication, although the difference between oil and grease is not as marked as at 80 revolutions per minute.

At 240 revolutions per minute (Fig. C27), the greater friction with grease is again apparent.

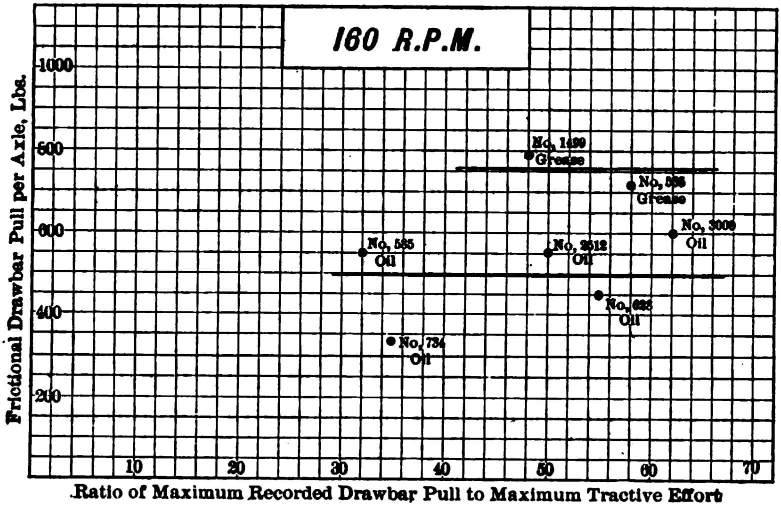


Fig. C 26.— Machine Friction.

It appears from an inspection of the plotted data that the use of grease may be expected to increase the friction losses per axle by from 75 to over 100 per cent.

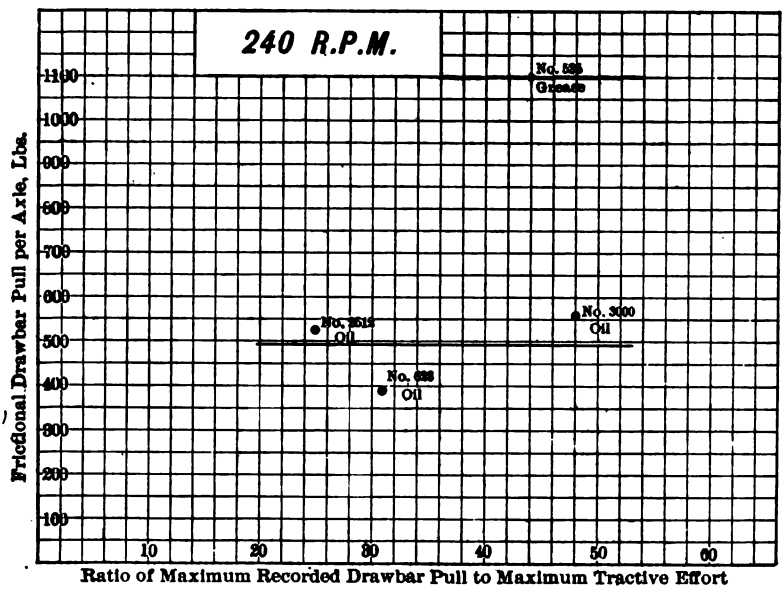


Fig. C 27.— Machine Friction.

COUNTERBALANCING.

The investigation of the counterbalancing of the passenger locomotives tested, was made by observing;

1—Critical speed.

2—Nosing or vibration at pilot.

3—Variation of driving wheel pressures on supporting wheels.

The methods of obtaining these data are given on page 57.

CRITICAL SPEED.

As previously noted, this name is given to the lowest speed at which the disturbing forces in the locomotive first affected the dynamometer. The critical speeds were as follows:

FREIGHT LOCOMOTIVES.		PASSENGER LOCOMOTIVES.	
No. 1499	176 R. P. M.	No. 2512	197 R. P. M.
" 734	176 " " "	" 535	180 " " "
" 585	167 " " "	" 628	200 " " "
" 929	96 " " "	" 3000	320 " " "

VIBRATION AT PILOT.

The curves showing the vibration at pilot are reproduced in the Appendices referring to the several passenger locomotives.

The maximum vibration at each speed, reduced to a standard distance from the front axle, is given in Table C23.

TABLE No. C 23.

Loco. No.	Maximum Vibration at Pilot, Inches			
	At 160 R. P. M.	At 240 R. P. M.	At 280 R. P. M.	At 320 R. P. M.
2512	——	.277	.296	——
535	.456	.592	.592	——
628	.093	.233	.465	——
3000	.235	.120	.110	.110

The location of the vibration pencil in relation to the front axle and the longitudinal center line of the locomotive is shown in Table C24.

The vibration of Nos. 2512 and 628, which had plate frames, is in the majority of cases an irregular curve, while the vibrations for Nos. 535 and 3000 were sinusoidal in form.

TABLE No. C 24.

Loco. No.	Dist. of Record. Pencil from Front Axle		Distance of Recording Pencil from Centre Line of Locomotive, Inches.
	In Inches.	In per Cent.*	
2512	185 1-2	108	43.75
535	215	125	42.00
628	183 5-8	107	43.00
3000	171 1-2	100	44.00

*Locomotive No. 3000 taken as unity.

The curves obtained from No. 3000 show the smallest vibration. The counterbalance weights of locomotive No. 535 were directly in line with the crank, whereas, the weights of the other three locomotives were angularly displaced. This refinement was responsible for the small vibrations of locomotives Nos. 2512, 628 and 3000. The tests, however, show that a four-cylinder locomotive can be perfectly balanced by distributing rotating counterweights between the two wheels in such a manner that the moments of all rotating weights shall balance each other in every plane.

VARIATION OF DRIVING WHEEL PRESSURES.

The thickness of the wires which were run between the driving and supporting wheels is shown in the several appendices, the maximum variation in thickness of wires being shown for each speed. These diagrams show, in a general way, the effectiveness of the vertical balancing of each locomotive. In the following, Table C25, the maximum variation of the thickness of the wires for each locomotive is given:

TABLE No. C 25.

Loco. No.	Maximum Variation in Thickness of Wire, Inches.			
	At 160 R. P. M.	At 240 R. P. M.	At 280 R. P. M.	At 320 R. P. M.
2512	——	.014	.012	——
535	.011	.026	.042	*
628	.014	.011	——	——
3000	.006	——	.004	.007

* Driving wheel left wire.

Owing to the rapid changes in the thickness of the wires for locomotives Nos. 2512 and 628, it would appear that the driving wheels vibrated on the supporting wheels. These two were the lightest passenger locomotives tested, which may be the reason for the apparent vibration. The variations in the thickness of the wires of locomotives Nos. 535 and 3000 were more regular than those of Nos. 2512 and 628, although the variation in thickness of wire for No. 535 was greater than that of the other locomotives. In one instance, the driving wheel of No. 535 left its supporting wheel.

The results seem to show that correct counterbalancing of a locomotive of the type commonly known as the four-cylinder balanced compound can be satisfactorily accomplished.

SUMMARY OF CONCLUSIONS.

An account of the tests and of the results derived from them will be found concisely stated in the several chapters preceding, and certain comparisons are made in the earlier paragraphs of this chapter. One desiring to apprehend the full significance of the data can not do better than give attention to these earlier portions of the volume, since any attempt to summarize must necessarily pass over important facts and must in some cases involve statements which, because of their incompleteness, are not entirely free from objection. With this understanding concerning the limitations which apply to any summary, the following concluding statements are appended.

BOILER PERFORMANCE.

1. Contrary to a common assumption, the results show that when forced to maximum power, the large boilers delivered as much steam per unit area of heating surface as the small ones.

2. At maximum power, a majority of the boilers tested, delivered 12 or more pounds of steam per square foot of heating surface per hour; two delivered more than 14 pounds; and one, the second in point of size, delivered 16.3 pounds. These values expressed in terms of boiler horse-power per square foot of heating surface are 0.34, 0.40 and 0.47 respectively.

3. The two boilers holding the first and second place with respect to weight of steam delivered per square foot of heating surface, are those of passenger locomotives.

4. The quality of steam delivered by the boilers of locomotives under constant conditions of operation is high, varying somewhat with different locomotives and with changes in the amount of power developed, between the limits of 98.3 per cent. and 99.0 per cent.

5. The evaporative efficiency is generally maximum when the power delivered is least. Under conditions of maximum efficiency, most of the boilers tested evaporated between 10 and 12 pounds of water per pound of dry coal. The efficiency falls

as the rate of evaporation increases. When the power developed is greatest, its value commonly lies between limits of 6 and 8 pounds of water per pound of dry coal.

6. The observed temperature of the fire-box under low rates of combustion lies between the limits of 1400 degrees F. and 2000 degrees F., depending apparently upon characteristics of the locomotive. As the rate of combustion is increased, the temperature slowly increases, maximum values generally lying between the limits of 2100 and 2300 degrees F.

7. The smoke-box temperature for all boilers, when worked at light power, is not far from 500 degrees F. As the power is increased, the temperature rises, the maximum value depending upon the extent to which the boiler is forced. For the locomotives tested, it lies in most cases between 600 and 700 degrees.

8. With reference to grate area, the results prove beyond question that the furnace losses due to excess air are not increased by increasing the area. In general, it appears that the boilers for which the ratio of grate surface to heating surface is largest are those of greatest capacity.

9. A brick arch in the fire-box results in some increase in furnace temperature and improves the combustion of the gases.

10. The loss of heat through imperfect combustion is in most cases small except as represented by the discharge from the stack of solid particles of fuel.

11. Relatively large fire-box heating surface appears to give no advantage either with reference to capacity or efficiency. The fact seems to be that the tube heating surface is capable of absorbing such heat as may not be taken up by the fire-box.

12. The value of the Serve tube over the plain tube of the same outside diameter, either as a means for increasing capacity or efficiency, was not definitely determined.

13. The draft in the front-end for any given rate of combustion as measured in inches of water, depends upon the proportions of the locomotive and the thickness and condition of the fire. Under light power, its value may not exceed an inch, but it increases rapidly as the power is increased. Representative maximum values derived from the tests lie between the limits of 5 inches and 8.8 inches.

14. Insufficient openings in the ash-pan and the mechanism of the front end, especially the diaphragm, are shown by the tests

to lead to the dissipation of considerable portions of the draft force.

THE ENGINE.

15. The indicated horse-power of the modern simple freight locomotive tested, may be as great as 1000 or 1100; that of a modern compound passenger locomotive may exceed 1600 horse-power.

16. The maximum indicated horse-power per square foot of grate surface lies, for the freight locomotives, between the limits of 31.2 and 21.1; for the passenger locomotives, between the limits of 33.5 and 28.1.

17. The steam consumption per indicated horse-power hour necessarily depends upon the conditions of speed and cut-off. For the simple freight locomotives tested, the average minimum is 23.7. The consumption when developing maximum power is 23.8 and when under those conditions which proved to be the least efficient, 29.0.

18. The compound locomotives tested, using saturated steam, consumed from 18.6 to 27 pounds of steam per indicated horse-power hour. Aided by a superheater, the minimum consumption is reduced to 16.6 pounds of superheated steam per hour.

19. In general, the steam consumption of simple locomotives decreases with increase of speed, while that of the compound locomotives increases. From this statement it appears that the relative advantages to be derived from the use of the compound diminish as the speed is increased.

20. Tests under a partially opened throttle show that when the degree of throttling is slight, the effect is not appreciable. When the degree of throttling is more pronounced, the performance is less satisfactory than when carrying the same load with a full throttle and a shorter cut-off.

THE LOCOMOTIVE AS A WHOLE.

21. The percentage of the cylinder power which appears as a stress in the draw-bar, diminishes with increase of speed. At 40 revolutions per minute, the maximum is 94 and the minimum 77; at 280 revolutions per minute, the maximum is 87 and the minimum 62.

22. The loss of power between the cylinder and draw-bar is greatly affected by the character of the lubricant. It appears from the tests that the substitution of grease for oil upon axles and crank pins increases the machine friction from 75 to 100 per cent.

23. The coal consumption per dynamometer horse-power hour, for the simple freight locomotives tested, is at low speeds not less than 3.5 pounds nor more than 4.5 pounds, the value varying with running conditions. At the highest speeds covered by the tests, the coal consumption for the simple locomotives increased to more than 5 pounds.

24. The coal consumption per dynamometer horse-power hour, for the compound freight locomotives tested is, for low speeds, between 2.0 and 3.7 pounds. Results at higher speeds were obtained only from a two-cylinder compound, the efficiency of which under all conditions is shown to be very high. The coal consumption per dynamometer horse-power hour for this locomotive at the higher speeds increases from 3.2 to 3.6 pounds.

25. The coal consumption per dynamometer horse-power hour, for the four compound passenger locomotives tested, varies from 2.2 to more than 5 pounds per hour, depending upon the running conditions. In the case of all of these locomotives, the consumption increases rapidly as the speed is increased.

26. A comparison of the performance of the compound freight locomotives with that of the simple freight locomotives is very favorable to the compounds. For a given amount of power at the draw-bar, the poorest compound shows a saving in coal over the best simple which will average above 10 per cent., while the best compound shows a saving over the poorest simple which is not far from 40 per cent. It should be remembered, however, that the conditions of the tests, which provide for the continuous operation of the locomotives at constant speed and load throughout the period covered by the observations, are all favorable to the compound.

27. It is a fact of more than ordinary significance that a steam locomotive is capable of delivering a horse-power at the draw-bar upon the consumption of but a trifle more than 2 pounds of coal per hour. This fact gives the locomotive high rank as a steam power plant.

28. It is worthy of mention that the coal consumption per

horse-power hour developed at the draw-bar by the different locomotives tested presents marked differences. Some of these are easily explained from a consideration of the characteristics of the locomotives involved. Where the data is not sufficient to permit the assignment of a definite cause, there can be no doubt but that an extension of the study already made will serve to reveal it.

The results of the work accomplished at St. Louis have been presented with some analysis of the performance of each locomotive and such general comparisons as were suggested by the more important facts.

With the testing plant in its permanent location at Altoona, it is proposed to continue the work begun at St. Louis and to make further investigations of locomotive performance. The tests already made have suggested lines along which it would be profitable to continue further experimental work.

While the modern locomotive, both in this country and abroad, has been developed largely on the results of road tests and road experience, it is realized that the locomotive testing plant offers the best means of studying those factors which influence economy and power.

This volume is published with the hope that it may stimulate interest in locomotive testing, and lead to independent investigation and study of this very important subject.

INDEX.

A

Advisory Committee, 1.
affiliated members, 2, 64.
formation of, 62-65.
Alden absorption brakes, 32-34.
American Chemical Society, 93.
Society of Mechanical Engineers, 1, 62, 64.
Railway Master Mechanics Association, 1, 62, 63.
American Locomotive Co., 64, 112, 265, 615.
Analysis of coal 92-94, 110.
of gases, 75, 94.
A. T. & S. F., "Santa Fe" type, locomotive, 112, 113, 331-391.
atlantic type, locomotive, 112, 113, 463-541.
Awards, 3-6.

B

Balancing of locomotives, 57, 109, 720-722.
Baldwin compound locomotive, 463-541.
Baldwin Locomotive Works, 64, 112, 331, 463.
Barometer, 74, 88.
Berwind White Coal Mining Co., 110-111.
Boiler capacity, 693, 694.
volume, 84, 688, 692.
efficiency, 99, 694-696.
horse power, 99.
Boilers, comparison of, 692-703.
Brakes, Alden absorption, 32-34,121.
Brooks Locomotive Works, 196.
Bureau of Standards, National, 74.

C

Calibration of instruments, 72-75.
Calorific value of coal, 94.
of sparks, 94.
of cinders, 94.
Calorimeter, coal, 75.
steam, 57-59.
Car, Postal exhibit, 23.
Carbon monoxide, 697-699.
Carpenter, Prof., 90.
Chemical Society, American, 93.
Cinders and sparks, 93.
Civil engineering exhibit, 13, 15-18.

Clearance, measurement of, 78.
Coal analysis, 93, 110.
  weighing, 92.
  box, 59, 92.
  sample, 92.
Coal Mining Co., Berwind White, 110.
Cole compound locomotive, 615-686.
Cole, F. J., 615.
Committee, Advisory, 1, 62-65.
Comparisons and conclusions, 687-722.
Compensator for indicator motion, 55.
Compound locomotives, 704-716.
Conclusions, summary of, 723-727.
Conducting tests, 107-111.
Correction factor for quality of steam, 88, 90.
Counterbalance testing apparatus, 57, 109.
Counterbalancing, 720-722.
Crane, electric travelling, 41.
Cross compound locomotive, 265-330.
Cylinders, measurement of, 77, 80.

D

Data, methods of recording. 76-105.
Dashpot, for safety bar, 34-36, 109, 122.
  dynamometer, 47.
De Glehn, M., 392.
De Glehn locomotive, 8, 112, 392-462.
Delays in tests, 119, 123.
Designation, laboratory, 125, 395.
Draft, 700-702.
Draft gages, 75. 88.
Drawbar pull, weighing, 95.
Drawings and maps, exhibit, 13, 15-18.
Du Bosquet, M., 392.
Dynamometer, traction, 42-47, 95, 117, 122.
  capacity, 43.
  drawbar, 43.
  diagram, 53.
  paper mechanism, 47-53.
  recording table, 50.
Dynamometer horse power, 102.

E

Efficiency, locomotive, 104.
  machine, 104.
Emery fulcrums, 42.
Engineers, American Society of Mechanical, 1, 62. 64.
Engines, comparison of, 703-710.
England, Commissioner for, 65, 113.
Equivalent evaporation, 99.
Evaporation, 98-99.
  factor of, 97.
Events of stroke, 95.

Exhibit of maps and drawings, 13, 15-18.
Pension Department, 18-23.
postal car, 23.
Savings Fund, 23.
Y. M. C. A., 13.
De Glehn locomotive, 8.
West Phila., Yards model, 8-10.
N. Y. Terminal Station model, 10-14.
Penna., N. Y. & Long Island tunnel model, 10, 16.
Extension track, 29-31.

F

Factor of correction for quality of steam, 88, 90.
Factor of evaporation, 97.
Force, testing, 2, 66-68.
Foundations of testing plant, 24, 117.
Friction, machine, 104.
France, Commissioner General for, 65, 113.
Northern Railway of, 392.
Fuel, analysis, 93, 110.

G

Gases, smokebox, analysis, 94.
Gages, draft, 75, 88.
steam, 61, 73.
Germany, Imperial Commissioner General for, 65, 113.
Goss, Prof. W. F. M., 56.
Graphical logs of test, 107.
Grate areas, 690.
Grease lubrication, 716-719.

H

Hanover compound locomotive, 113, 542-614.
Hannoversche Maschinenbau Act. Gesell, 113, 542.
Heating surface, measurement, 83.
Henschel & Sohn, 113.
Horse power, boiler, 99.
dynamometer, 102.
indicated, 101.

I

Indicated horse power, 101.
Indicators, steam, 72.
Indicator reducing motions, 54-56.
Installation of testing plant, 117.
Instruments, calibration of, 72-75.
used in tests, 42-61.
Integrator, 53.

Superheated steam, 89, 546-548, 556-559.
Supporting wheels, 28.
Supporting axles, 28.

T

Tandem compound locomotive, 112.
Temperature observations, 86, 107, 699.
Testing force, 2, 66-68.
Testing plant, 24-41.
Tests, conducting, 107-111.
Thermo couples, 60, 74, 87.
Thermometers, 74.
Thompson calorimeter, 75.
Throttling calorimeter, 57-59.
Throttling tests, 69-71, 702, 709.
Track, extension and removable, 29-31.
Tractive effort, maximum, 105, 689.
Tubes, measurement, 81.
    serve, 82, 392.
Tunnel, section, 13, 17.
    model, 10, 16.

V

Valves, measurement of, 80.
Vibration recording apparatus, 57.
Voluntary Relief Dept., exhibit, 18-20.
Von Borries valve gear, 542.

W

Walschaert valve gear, 395.
Water control valve, 40, 120.
    weighing, 59, 94.
    measuring tanks, 59.
    Meters, 39, 94.
    purifier, 39, 111, 703.
    piping, 39.
West Phila. Yards, model of, 8-10.
Weights of locomotives, 689.
Wind resistance, 95.

Y

Yards, West Phila., model, 8-10.
Y. M. C. A., exhibit, 13.